Annex 526

“Fiscal Monitor: Climate Crossroads: Fiscal Policies in a Warming World”,
International Monetary Fund, October 2023

INTERNATIONAL MONETARY FUND

FISCAL MONITOR

Climate Crossroads: Fiscal Policies in a Warming World

2023
OCT

Cover and Design: IMF CSF Creative Solutions Division
Composition: Absolute Service, Inc.; and AGS, An RR Donnelley Company

Cataloging-in-Publication Data
IMF Library

Names: International Monetary Fund.
Title: Fiscal monitor.
Other titles: World economic and financial surveys, 0258-7440
Description: Washington, DC : International Monetary Fund, 2009- | Semiannual | Some issues also have thematic titles.
Subjects: LCSH: Finance, Public—Periodicals. | Finance, Public—Forecasting—Periodicals. | Fiscal policy—Periodicals. | Fiscal policy—Forecasting—Periodicals.
Classification: LCC HJ101.F57

ISBN: 979-8-40025-028-6 (paper)
979-8-40025-030-9 (PDF)
979-8-40025-032-3 (ePub)

Disclaimer: The *Fiscal Monitor* is a survey by the IMF staff published twice a year, in the spring and fall. The report analyzes the latest public finance developments, updates medium-term fiscal projections, and assesses policies to put public finances on a sustainable footing. The report was prepared by IMF staff and has benefited from comments and suggestions from Executive Directors following their discussion of the report on September 26, 2023. The views expressed in this publication are those of the IMF staff and do not necessarily represent the views of the IMF's Executive Directors or their national authorities.

Recommended citation: International Monetary Fund (IMF). 2023. *Fiscal Monitor: Climate Crossroads: Fiscal Policies in a Warming World.* Washington, DC: IMF, October.

Publication orders may be placed online, by fax, or through the mail:
International Monetary Fund, Publication Services
PO Box 92780, Washington, DC 20090, USA
Telephone: (202) 623-7430 Fax: (202) 623-7201
E-mail: publications@imf.org
www.imfbookstore.org
www.elibrary.imf.org

CONTENTS

Figures

Tables

Online-Only Annexes

ASSUMPTIONS AND CONVENTIONS

The following symbols have been used throughout this publication:

. . . to indicate that data are not available

— to indicate that the figure is zero or less than half the final digit shown, or that the item does not exist

– between years or months (for example, 2008–09 or January–June) to indicate the years or months covered, including the beginning and ending years or months

/ between years (for example, 2008/09) to indicate a fiscal or financial year

"Billion" means a thousand million; "trillion" means a thousand billion.

"Basis points" refers to hundredths of 1 percentage point (for example, 25 basis points are equivalent to ¼ of 1 percentage point).

"n.a." means "not applicable."

Minor discrepancies between sums of constituent figures and totals are due to rounding.

As used in this publication, the term "country" does not in all cases refer to a territorial entity that is a state as understood by international law and practice. As used here, the term also covers some territorial entities that are not states but for which statistical data are maintained on a separate and independent basis.

FURTHER INFORMATION

Corrections and Revisions

The data and analysis appearing in the *Fiscal Monitor* are compiled by IMF staff at the time of publication. Every effort is made to ensure their timeliness, accuracy, and completeness. When errors are discovered, corrections and revisions are incorporated into the digital editions available from the IMF website and on the IMF eLibrary. All substantive changes are listed in the Table of Contents of the online PDF of the report.

Print and Digital Editions

Print

Print copies of this *Fiscal Monitor* can be ordered from the IMF Bookstore at imfbk.st/536672.

Digital

Multiple digital editions of the *Fiscal Monitor*, including ePub, enhanced PDF, and HTML, are available on the IMF eLibrary at www.elibrary.imf.org/OCT23FM.

Download a free PDF of the report and data sets for each of the figures therein from the IMF website at www.imf.org/publications/fm, or scan the QR code below to access the *Fiscal Monitor* web page directly:

Copyright and Reuse

Information on the terms and conditions for reusing the contents of this publication are at www.imf.org/external/terms.htm.

PREFACE

The projections included in this issue of the *Fiscal Monitor* are drawn from the same database used for the October 2023 *World Economic Outlook* and *Global Financial Stability Report* (and are referred to as "IMF staff projections"). Fiscal projections refer to the general government, unless otherwise indicated. Short-term projections are based on officially announced budgets, adjusted for differences between the national authorities and the IMF staff regarding macroeconomic assumptions. The fiscal projections incorporate policy measures that are judged by the IMF staff as likely to be implemented. For countries supported by an IMF arrangement, the projections are those under the arrangement. In cases in which the IMF staff has insufficient information to assess the authorities' budget intentions and prospects for policy implementation, an unchanged cyclically adjusted primary balance is assumed, unless indicated otherwise. Details on the composition of the groups, as well as country-specific assumptions, can be found in the Methodological and Statistical Appendix of the October 2023 *Fiscal Monitor*.

The *Fiscal Monitor* is prepared by the IMF Fiscal Affairs Department under the general guidance of Vitor Gaspar, Director of the Department. The project was directed by Ruud de Mooij, Deputy Director, and Era Dabla-Norris, Assistant Director. The main authors of Chapter 1 in this issue are W. Raphael Lam (team lead) and Christine Richmond (team lead), David Amaglobeli, Simon Black, Yongquan Cao, Ximing Dong, Daniel Garcia-Macia, Christophe Hemous, Samir Jahan, Pedro Juarros, Salma Khalid, Koralai Kirabaeva, Antung Anthony Liu, Emanuele Massetti, Diego Mesa Puyo, Danielle Minnett, Anh Nguyen, Sandeep Saxena, Sunalika Singh, Alexandra Solovyeva, Nate Vernon, Chenlu Zhang, and Karlygash Zhunussova, with contributions from Fotios Kalantzis (European Investment Bank), Brent Meyer (Federal Reserve Bank of Atlanta), Xuguang Simon Sheng (American University), Pawel Smietanka (Deutsche Bundesbank), Sonya Waddell (Federal Reserve Bank of Richmond), Daniel Weitz (Federal Reserve Bank of Atlanta), and Marcin Wolski (European Investment Bank).

The Methodological and Statistical Appendix was prepared by Zhonghao Wei under the guidance of Xuehui Han. Jiae Yoo provided excellent communications support. Meron Haile and Andre Vasquez provided excellent coordination and editorial support. Wala'a El Barasse from the Communications Department led the editorial team and managed the report's production, with editorial and production support from Michael Harrup, Katy Whipple, Linda Long, and Absolute Service, Inc. Fabio Bolzan, Thanayi Jwahir, Jinsol Kim, and Felipe Leon from the Corporate Services and Facilities Department provided excellent support to the infographics.

Inputs, comments, and suggestions were received from other departments in the IMF, including area departments—namely, the African Department, Asia and Pacific Department, European Department, Middle East and Central Asia Department, and Western Hemisphere Department—as well as the Communications Department, Institute for Capacity Development, Legal Department, Monetary and Capital Markets Department, Research Department, Secretary's Department, Statistics Department, and Strategy, Policy, and Review Department. Chapter 1 of the *Fiscal Monitor* also benefited from comments by Joe Aldy (Harvard University), Scott Barrett (Columbia University), Dora Benedek (IMF), Stefano Carattini (Georgia State University), Kelly Clark (University of California, Los Angeles), Carolyn Fischer (World Bank), Stephie Fried (Federal Reserve Bank of San Francisco), Larry Goulder (Stanford University), Stephane Hallegatte (World Bank), Felix Kubler (University of Zurich), Neil Mehrotra (Federal Reserve Bank of Minneapolis), Debora Revoltella (European Investment Bank), James Roaf (IMF), Thomas Sterner (University of Gothenburg), David Victor (University of California, San Diego), and participants of the IMF workshop on "Designing Fiscal Policies on the Road to Net Zero" in July 2023. Both projections and policy considerations are those of the IMF staff and should not be attributed to Executive Directors or to their national authorities.

FOREWORD

For all countries, it is becoming hard to balance public finances. The difficulties originate in ever-growing demand for public spending, associated with high expectations about what the state can and should do, elevated debts, and high-for-long interest rates and political red lines on taxes. But the way the government budget constraint binds varies widely across countries. In some cases, it is binding with the government having insufficient resources to pay urgent bills and no access to market financing. These countries are often small and poor. For example, in many low-income countries interest expenses represent a large and growing fraction of tax revenues. In other cases, while immediate financial pressures are absent, the perpetuation of current policies entails an unsustainable fiscal path. These countries are, in general, large and rich. In addition, there is another important consideration when pondering budgetary policies. In most countries, tighter fiscal policies are needed, not only to reconstitute buffers and contain public finance risks, but also to contribute to central banks' efforts in favor of a timely return to inflation targets.

Debts are generally elevated around the world, and borrowing costs are rising. Global public debt is expected to turn up in 2023. Why? It would be accurate to answer that the rising trend is due to the major global economies (including the United States and China). Indeed, world debt is projected to increase by about 1 percentage point of GDP per year over the medium term. But, excluding the two largest economies, the ratio would instead decline by about ½ percentage point annually. Nevertheless, it would be more *relevant* to state that the turning up of deficits reflects slowing growth, rising real interest rates, and budget deficits dipping further into the red. The bottom line is that global public debt is now substantially higher, and it is projected to grow considerably faster than in prepandemic projections. At the projected pace, the global public debt ratio would be approaching 100 percent of GDP by the end of the decade.

The *Fiscal Monitor* looks at the fiscal implications from the green transition. The baseline is business as usual. Under such an assumption, it is possible to identify *ambition* gaps—the difference between countries' own nationally defined contributions and what is required to deliver on the Paris Agreement goals—and *policy* gaps—the difference between the national targets and the outcomes achievable under "business-as-usual" conditions. In sum, the baseline scenario fails to deliver net zero, with catastrophic consequences. Our report shows that scaling up the current policy mix—heavy on subsidies and other components of public spending—to deliver net zero leads to an accumulation of public debt by 40–50 percentage points of GDP for a representative advanced economy and for a representative emerging market economy by 2050.

The *Fiscal Monitor* argues that to partially circumvent this terrible trade-off, it is necessary to rely on a combination of policy instruments. Carbon pricing is a necessary component of the policy mix, but it is not sufficient. It must be complemented by instruments aimed at correcting remaining market failures. Fiscal support is also necessary to facilitate the unavoidable costly adjustments required of vulnerable households, workers, communities, and corporations. *Climate Crossroads: Fiscal Policies in a Warming World* presents illustrative combinations of policies that limit the increase in the public debt ratio to the range of 10–15 percentage points of GDP by 2050. That is a pressure that looks manageable through the adjustment of other parts of the budget.

Countries with limited fiscal space, low tax capacity, and expensive or nonexistent access to market financing face large adaptation costs. In many cases, these countries also have to deal with financial difficulties in their efforts to pursue sustainable, inclusive, and resilient development. These countries should prioritize and target spending (for example, eliminating fuel subsidies). They should also intensify their efforts to improve tax capacity with special emphasis on institutional building and enlarging tax bases (see IMF Staff Discussion Note "Building Tax Capacity in Developing Countries").

The private sector has a crucial role to play in a successful green transition. Public policies should provide a framework that favors private sector participation in investment and financing. In 2021 and 2022, the IMF has supported the efforts in more than 150 member states to upgrade tax capacity and to strengthen the market for Treasury liabilities. See the October 2023 *Global Financial Stability Report* for an overview on climate finance.

Ahead of the Conference of the Parties 28, it is important to reiterate that a global pragmatic side agreement among large players—such as the United States, China, India, the European Union, and the African Union—could make a decisive contribution. By incorporating a carbon price floor, the global agreement would provide the most effective and efficient policy instrument to become a focal point for policy action in the world. By including financial and technological transfers and revenue-sharing mechanisms, it could ease the financial divide and contribute to the achievement of the United Nation's Sustainable Development Goals, including the eradication of poverty and hunger.

The IMF has an important role to play at the center of the international monetary system, to help preserve sound public finances and financial stability. It is an essential piece of the global safety net. Urgent support from members is necessary to increase quota resources and secure funding for the concessional Poverty Reduction and Growth Trust and the Resilience and Sustainability Trust.

The logic of the three-way policy trade-off—or policy trilemma—described in the first lines of this foreword applies beyond climate. In fact, it applies to any policy goal that implies additional budget spending. Faced with myriad spending pressures, political red lines limiting taxation, at an insufficient level, translate directly into larger deficits that push debt to ever-rising heights.

Something must give to balance the fiscal equation. Policy ambitions may be scaled down or political red lines on taxation moved if financial stability is to prevail. The *Fiscal Monitor* shows that a smart policy mix maps the way out of the trilemma.

Vitor Gaspar
Director of the Fiscal Affairs Department

EXECUTIVE SUMMARY

Global warming threatens the planet and human livelihoods, with 2023 set to become the warmest year on record. Recognizing the threat, countries have set climate goals—for example, many countries have committed to reducing greenhouse gas emissions to net zero by midcentury—and have taken a range of policy actions. However, current and announced policies will fall short of achieving the 2015 Paris Agreement's temperature goals. Containing global warming will ultimately benefit everyone by mitigating the potential catastrophic consequences of climate change. However, it necessitates a radical economic transformation that could impose costs and benefits unevenly across people, firms, regions, and countries. With private financing playing a decisive role, the transition to low-carbon energy sources will require strong complementarities between public and private actors.

Relying on Spending Measures Will Be Costly

Many countries are facing high debt, rising interest rates, and weaker growth prospects. Debt-to-GDP ratios are projected to rise by 1 percentage point a year globally during 2023–28, faster than foreseen before the pandemic. These headwinds complicate efforts to tackle climate change.

Several economies are pursuing emission reduction policies that rely heavily on spending measures, such as increasing public investment and subsidies for renewable energy. Policies to reduce emissions are welcome efforts. Yet, in some cases, they entail large fiscal costs. Policymakers thus face a fundamental trade-off: On the one hand, relying mostly on spending-based measures to reach net zero goals by midcentury will become increasingly costly, possibly raising public debt by 45–50 percent of GDP for a representative large-emitting country, putting debt on an unsustainable path. On the other hand, limited climate action would leave the world exposed to adverse consequences from global warming. Macroeconomic risks would concomitantly rise. The trade-off can be relaxed by the use of carbon pricing, which is cost-effective in reducing emissions while also generating revenues to relieve the debt burden. However, carbon pricing is often unpopular, thus transforming the trade-off into a trilemma between achieving climate goals, fiscal sustainability, and political feasibility.

Such challenges are stark for emerging market and developing economies given their growth and development priorities. These economies also need to adapt to the consequences of climate change, adding to the already-sizable investment needs to meet the Sustainable Development Goals. They also have limited access to low-carbon technologies, even though existing technologies can enable countries to achieve about 90 percent of the emission cuts required by 2030 to meet the temperature goals. Fossil fuel-producing countries will also see sharp declines in commodity revenues if the world gets on track to achieving net zero emissions, presenting substantial challenges for public finances and economic diversification.

A Cleaner Future Is Possible with the Right Policies in Place

No single policy measure on its own can fully deliver on climate goals. The chapter presents a practical mix of policies accounting for their economic efficiency, administrative practicality, and political feasibility, among other attributes. From a macro-fiscal perspective, while policies should be tailored to country circumstances, carbon pricing should be an integral part of the policy mix. Although carbon pricing is necessary, it is not sufficient and should be complemented by other mitigation instruments—such as feebates, green subsidies, and regulation standards, among others—to promote innovation and deployment of low-carbon technologies and address market failures and network externalities. Fiscal transfers to vulnerable workers, families, and communities can help address concerns from higher energy prices. Successful experiences from countries at various stages of development show that this approach can help mitigate political hurdles associated with carbon pricing. These insights stand to benefit not only the nearly 50 countries already with carbon pricing schemes in place (that will require further increases) but also the more than 23 countries currently contemplating their introduction.

Fiscal costs vary depending on the mix of revenue and spending policies. Analyses show that an appropriate mix and sequencing of revenue- and spending-based climate measures enacted now can help limit the fiscal costs of delivering the necessary emission reductions. In an indicative scenario, public debt in advanced economies would rise by 10–15 percent of GDP by 2050 (equivalent to an increase of primary deficits by 0.4 percentage point of GDP a year, on average, through 2050). Advanced economies with ample fiscal space could likely accommodate such a policy mix. Others with less fiscal space will need to prioritize spending (such as removing fossil fuel subsidies) and raise revenues to maintain debt sustainability. In either case, delayed action on carbon pricing would be very costly. Each year of delay is estimated to contribute an additional 0.8–2.0 percent of GDP a year to public debt.

Emerging market economies make up a notable share of global emissions. The expected increase in debt from a package of climate policies is estimated to be similar to advanced economies, at about 15 percent of GDP by 2050. The debt estimates are subject to large uncertainty, reflecting differences in investment and subsidies, compensation to households, fiscal space, and dependence on fossil fuels. The composition of the debt impact is notably different from advanced economies on account of higher mitigation investment needs, larger carbon revenue potential, and higher borrowing costs that are sensitive to debt. An increase in debt will be particularly challenging for emerging market and developing economies already experiencing high debt and rising interest costs, alongside sizable adaptation needs. These findings reinforce the need for improved expenditure efficiency, revenue mobilization, a greater role for private sector financing, and external financial support alongside knowledge transfers and diffusion of established low-carbon technologies. The IMF can also help by providing long-term financing under the Resilience and Sustainability Trust. Large uncertainty—arising from policy impacts and nonlinear impacts of climate change—suggests that incorporating climate action in debt sustainability analyses is crucial.

Governments Need to Facilitate the Green Transition for Firms

Firms play a crucial role in decarbonization efforts, and governments need to encourage firms to make the necessary transformation to a low-carbon future. In this regard, firm-level analysis indicates that regulations mandating firms to set or monitor emission targets are often associated with higher firm investment in low-carbon technologies. The surge in energy prices in 2022 has shown that firms are able to invest in energy efficiency and reduce energy consumption when confronted with large energy price shocks, suggesting that regulations, incentives, and carbon pricing schemes can accelerate firm decarbonization efforts.

Fiscal incentives (via tax credits or subsidies) can boost firm investment in low-carbon technologies, especially when firms feel confident about the impact of policies on their investment plans. Domestic policies therefore need to be well communicated to firms, including their horizon, coverage, and criteria for eligibility. Targeting fiscal incentives can help minimize their fiscal costs, as some firms will invest even without government support. This shows that both policy design and implementation matter. Green subsidies must be consistent with World Trade Organization rules to avoid unintended distortions to trade and a subsidy race across nations.

Climate change is a shared responsibility. No single country is able to solve it alone. Policymakers must accelerate and coordinate their efforts on all fronts to ensure a sustainable and resilient world for future generations.

This page intentionally left blank

CHAPTER 1

CLIMATE CROSSROADS: FISCAL POLICIES IN A WARMING WORLD

Introduction

The world is warming. The year 2023 is turning out to become the warmest one on record. According to the World Meteorological Organization, temperatures are likely to increase by more than 1.5 degrees Celsius (°C) above preindustrial levels within the coming five years. The Intergovernmental Panel on Climate Change predicts that under current trends, temperatures could increase by 3°C or more, relative to preindustrial levels, by 2100.[1] Such increases will have detrimental effects on lives and livelihoods through increased morbidity and mortality due to more prevalent infectious diseases and natural disasters; lower productivity in agriculture, fishing, and work exposed to extreme temperature conditions; and more frequent disruptions from extreme weather events and rising sea levels. The likelihood of climatic "tipping points"—such as the melting of glaciers and ice caps—increases with greater warming, bringing potential catastrophic consequences for life on the planet (IPCC 2021; Georgieva 2022; McKay and others 2022; Ditlevsen and Ditlevsen 2023).

Countries have recognized the need for urgent action to address global warming. In the 2015 Paris Agreement, they agreed to "hold the increase in the global average temperature to well below 2°C above preindustrial levels" and ideally to 1.5°C to avert catastrophic outcomes. Countries have also committed to longer-term targets for net zero emissions—cutting greenhouse gas emissions released into the atmosphere to as close to zero as possible, with the remaining emissions captured and stored—by about midcentury. Despite progress, large gaps in ambition and implementation exist (Figure 1.1).

Achieving temperature goals will require a fundamental transformation of consumption, production, and investment by households, firms, and governments over the coming years. Investment and innovation in green sectors, processes, and products, along with behavioral changes, should decrease emissions but will come at the expense of existing brown activities (Aghion and Howitt 2005; Stern and Valero 2021), creating new opportunities and risks (Mercure and others 2018; Gourinchas, Schwerhoff, and Spilimbergo 2023).

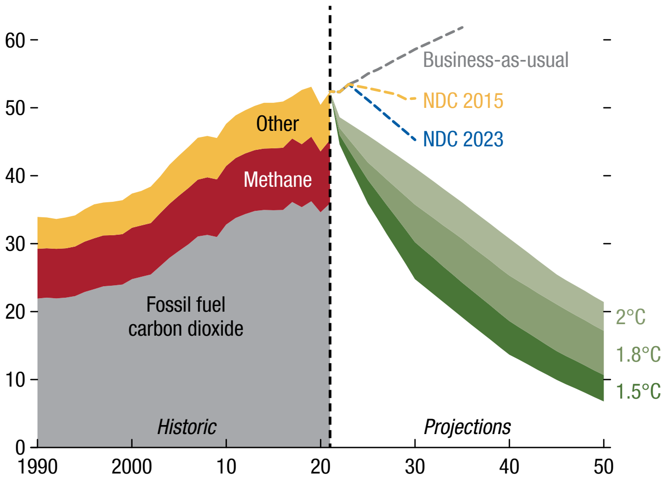
Fiscal policies will play a central role in such a transformation, including by creating a larger role for private sector financing (October 2023 *Global Financial Stability Report*, Chapter 3). A key question is how governments can encourage firms and households to decarbonize, through spending, taxation, or regulation or a combination of the three (Figure 1.2). The impact on public finances hinges critically on the decarbonization actions by firms and households as well as their responses to policies. A push for energy security is prompting countries to pursue a faster, but likely more bumpy, green transition (that is, a transition to low carbon energy and building resilience against climate risks), raising concerns that firms may not be ready to face the resulting higher energy costs. At the same time, fiscal policies will play a key role in mitigating the cost of transition for households and firms and guiding private sector decisions. Many countries—notably low-income countries and small developing states—have multiple competing development needs alongside the imperative to adapt to climate change, suggesting scope for global cooperation. Fiscal interventions in all these areas will need to respect government budget constraints. Assessing the fiscal implications of policies to achieve climate objectives is particularly pertinent at this juncture, as many countries are facing elevated debt levels, high inflation, and weak growth prospects. Rising geopolitical fragmentation also poses risks to cross-border climate technology diffusion (October 2023 *World Economic Outlook*, Chapter 3).

Against this background, this chapter addresses the following questions:

- *Can countries rely mostly on spending-based climate policies to achieve net zero emissions?*
- *How can policymakers design politically acceptable climate policies in a cost-effective and fiscally sustainable way?*
- *How can governments facilitate the green transition among firms?*

[1]The panel's central estimates under the "SSP2-4.5" scenario have a range for the increase as 2.1–3.5°C.

Figure 1.1. Annual Global Greenhouse Gas Emissions, 1990–2050
(Billions of tons of carbon dioxide emissions equivalence)



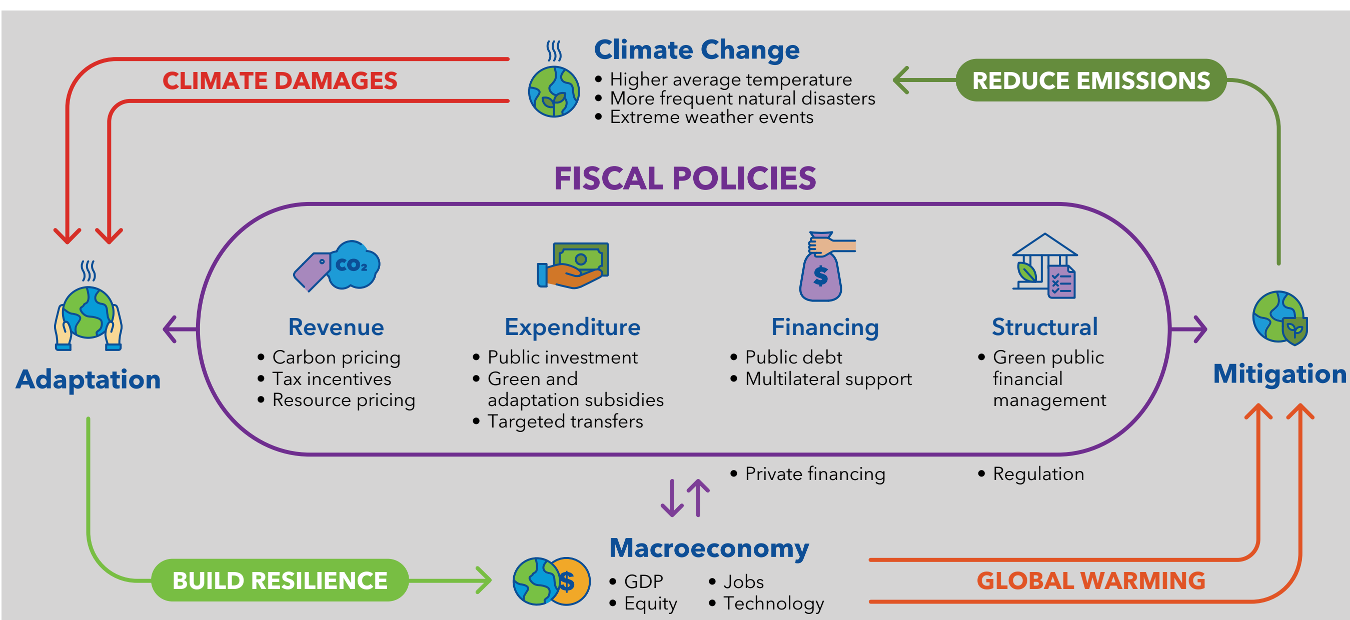
Sources: Intergovernmental Panel on Climate Change; Black, Parry, and Zhunussova 2023; and IMF staff estimates.
Note: The figure shows estimates from projection using the IMF–World Bank Climate Policy Assessment Tool. °C = degrees Celsius; NDC = nationally determined contribution.

The main contributions of the chapter include (1) conducting granular analyses to illustrate and quantify the fiscal impact and public debt implications across country groups during the green transition; (2) assessing the evolving optimal mix of climate instruments from a macrofiscal perspective in light of their cost-effectiveness, political acceptability, and other attributes; and (3) examining interactions among public incentives, green investment, and adoption of technologies by firms based on microlevel analyses, strengthening the case for using a mix of fiscal instruments. While the chapter focuses on domestic policies, it also highlights the role of international coordination in mitigation policies.

Are Current Policies Scalable on the Road to Net Zero?

Despite country efforts to meet their national climate goals, estimates using the IMF–World Bank Climate Policy Assessment Tool put the combined reduction in emissions as a result of existing and planned mitigation policies, relative to a baseline for 2030 without such policies, at 13 percent across the

Figure 1.2. The Green Transition Brings Close Interactions among Fiscal Policies, Climate, and Macroeconomy



Source: IMF staff compilations.
Note: The green transition involves reducing greenhouse gas emissions and building resilience against climate risks. Economic activity emits greenhouse gases, leading to environmental damages, which could pose adverse economic impact. Mitigation policies aim to reduce emissions, while adaptation policies enhance resilience for countries to limit the disruptions to the economy. These point to intertwined linkages between fiscal policies, the macroeconomy, and climate outcomes.

Group of Twenty (Figure 1.3).[2] This falls significantly short of the 25–50 percent reduction by 2030 needed to achieve the Paris Agreement's temperature goals (Black, Parry, and Zhunussova 2023). The largest emitters, including *China,* the *European Union, India*, and the *United States,* together account for more than 60 percent of global emissions by 2030. The share of emerging market economies is expected to reach almost 70 percent by 2035, signifying their importance for global mitigation efforts.

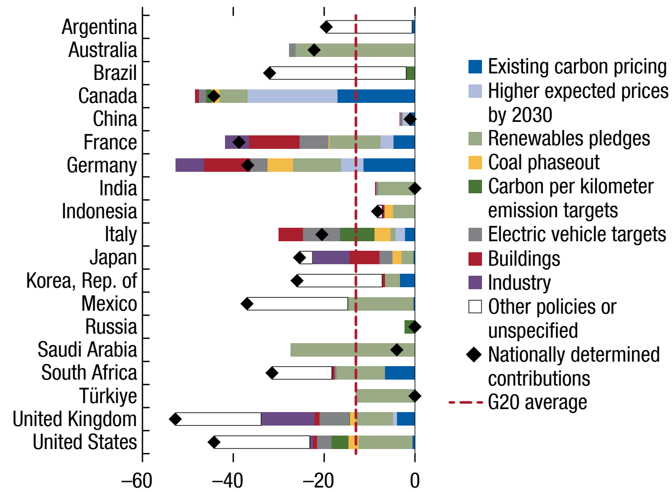
Countries have pursued different policy mixes to curb emissions to date. An increasing number of countries have put an explicit carbon price on greenhouse gas emissions, but their carbon-pricing schemes cover only one-quarter of global emissions, and the average price is $20 a ton—well below the level of coverage and price needed to achieve net zero goals (IEA 2021; Black and others 2022a). Instead of raising prices on carbon emissions, some large economies have adopted policy packages that largely rely on spending-based measures such as investments in green infrastructure, public funding for investments in clean energy, and green subsidies (or tax expenditures) to provide incentives for private investment and adoption of low-carbon technologies. For example, the Inflation Reduction Act of 2022 represents the largest federal policy to date in the *United States* (costing nearly $400 billion over 10 years) to tackle climate change and envisages higher investment in clean energy and electric vehicles (Bistline, Mehrotra, and Wolfram 2023). Rapid deployment of clean energy-generating capacity and achieving the full potential of the Inflation Reduction Act will hinge on overcoming real-world challenges, such as delays in permitting and electricity transmission siting. The *European Union* has supplemented its carbon-pricing approach by proposing a Green Deal Industrial Plan comprising tax breaks and relaxation of state aid (subsidy) rules in the coming years to boost renewable investment by the private sector. *China* has scaled up green public investment and subsidized the deployment of solar energy over the last decade under its Made in China 2025 initiative. Some countries also have targets to reduce energy use in buildings (*France*, *Germany*, *Italy*, *Japan*), while others have set regulations for new buildings to have net zero emissions by 2030 (*Canada*, *Korea*, *South Africa*, *United States*) (Online Annex 1.1).

These policies contribute toward reducing emissions and some are necessary to achieve specific targets, although they are not always cost-effective. For example, the carbon price equivalent for the sectoral policies shown in Figure 1.3 varies significantly, implying countries could have achieved the same mitigation goal at lower cost (Black and others 2022b).

Estimates by the International Energy Agency suggest that achieving net zero emissions by 2050 will require an additional global investment in mitigation of $2 trillion to $2.5 trillion over the next decade. Partly because of the substantial government budget constraints (discussed in the remainder of the chapter), private investment in low-carbon technologies—working in tandem with governments through fiscal incentives and regulatory measures—will need to account for the lion's share of this investment.

Figure 1.3. Impacts of Current Policies, Relative to No Climate Policies, on Carbon Dioxide Levels in 2030

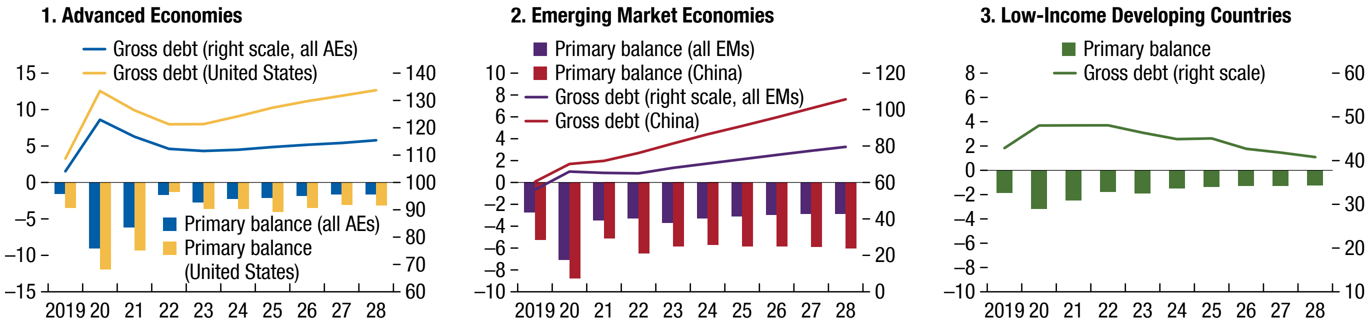
(Percent reduction relative to no climate policies)



Source: IMF staff estimates using the IMF–World Bank Climate Policy Assessment Tool (see Online Annex 1.1).
Note: "Other policies or unspecified" includes policies not quantified here or not yet specified by national authorities. The no-climate-policy counterfactual implies that countries would stop any existing carbon pricing. The figure includes estimates of emission reductions from the power and industry sectors under the US Inflation Reduction Act. G20 = Group of Twenty.

[2]The IMF–World Bank Climate Policy Assessment Tool is a spreadsheet-based model that helps policymakers assess, design, and implement climate mitigation policies, allowing them to estimate the effects of such policies for more than 200 countries. It includes impacts on energy demand and prices, emissions of carbon dioxide and other greenhouse gases, fiscal revenues, GDP, and welfare, as well as distributional impacts on households and industries and development co-benefits like health benefits from reductions in local air pollution and road accidents. See Black and others (2023b) for details.

Figure 1.4. Historic and Projected Public Debt and Primary Balance, 2019–28
(Percent of GDP)



Source: IMF, World Economic Outlook database.
Note: AEs = advanced economies; EMs = emerging markets.

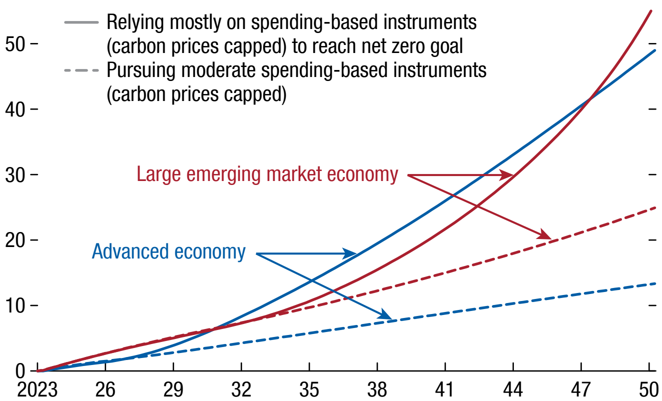
Elevated public debt levels across most countries are complicating climate challenges at the current juncture. Following a decline in 2021–22, global public debt ratios are projected to rise again in 2023 and to continue to increase by 1 percentage point a year over the medium term, growing faster than foreseen before the pandemic (Figure 1.4). Fiscal adjustments are necessary over the medium term to rebuild fiscal buffers. However, this leaves limited resources to achieve climate goals in many instances.

Relying largely on expenditure-based measures to achieve net zero emissions by midcentury would raise public debt-to-GDP ratios sharply and put debt sustainability at risk, as shown in an illustrative simulation (Online Annex 1.2).[3] For a representative advanced economy, the simulation considers a policy package that combines a carbon price of $75 a ton by 2030, maintained at that level until 2050, with spending-based mitigation policies that scale up public investment and subsidies. Private sector investment responds to government policies, and accounts for the lion's share of the total green investment needed for decarbonization in the model. The simulation considers two scenarios with regard to spending policies: a substantial scaling up of green investment and subsidies to reach the net zero goal (solid blue line in Figure 1.5), and a moderate increase in such spending to contain the rise in debt (dashed blue line in Figure 1.5). The former scenario entails a much larger fiscal cost, a significant rise in the debt-to-GDP ratio (by 45 percentage points by 2050), and an associated pickup in government borrowing costs. Rising debt levels of the magnitude projected in the scenario are likely unsustainable. A gradual erosion of existing fuel tax bases as the economy decarbonizes could exacerbate these risks.[4] In the scenario with a more moderate increase in expenditures, however, emissions would only fall by about 40 percent by 2050 from the current levels, insufficient to meet targets. Relying solely on carbon pricing to reach net zero would require a higher carbon price—at $280 per ton by 2050 according to simulations in Online Annex 1.2—that might be politically unpalatable in many countries, despite carbon pricing's effectiveness in reducing emissions and generating revenues. It could adversely affect output and lead to uneven transition costs among households, making carbon taxes—similar to other revenue measures—less popular to enact or expand (Känzig 2023; Metcalf 2023).

[3]The simulation employs a New Keynesian dynamic general equilibrium model with an energy input and a rich set of fiscal policies based on Traum and Yang (2015). In the model, energy is used in the production of final goods and generated from both green and brown sources. Each energy source employs private capital and labor, as well as public capital in the case of green energy (for example, electricity grids) and private investment subject to adjustment costs. Heterogeneity among households allows the distributional effects of climate policies to be analyzed. Fiscal policies include carbon pricing, green subsidies, public investment, and targeted transfers, as well as standard taxes on consumption, labor, and capital income. See details in Online Annex 1.2. Similar studies have been conducted for *France* (Pisani-Ferry and Mahfouz 2023) and the *United Kingdom* (Office of Budget Responsibility 2021), using country-specific assumptions. The October 2020 *World Economic Outlook* considers the impact of a near-term investment push on climate transition and the macroeconomy.

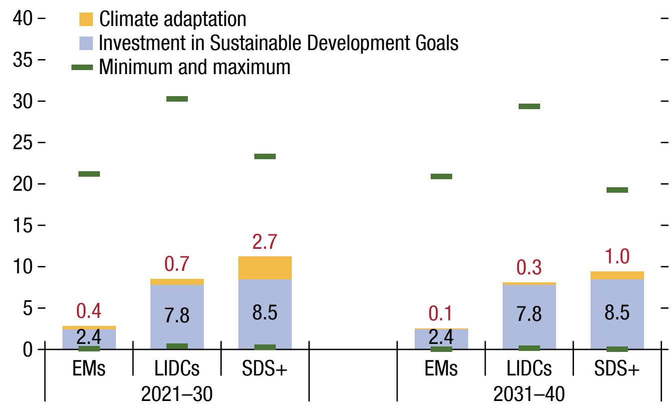
[4]If countries find alternative ways to finance the spending-based measures (other than through carbon taxes or deficit financing), the rise in debt levels will be smaller.

Figure 1.5. Illustrative Debt Dynamics When Expenditure-Based Climate Policies Are Expanded
(Percent of GDP)



Source: IMF staff simulations.
Note: The figure shows cumulative change in debt-to-GDP relative to a "business-as-usual" scenario based on simulations from a dynamic general equilibrium model (see Online Annex 1.2 for details). The lines for the advanced economy (large emerging market economy) cap the carbon price at $75 ($45) a ton. The solid lines scale up green public investment and subsidies (at 2 percent of GDP a year on average) to meet the net-zero-emissions target by 2050 (2060 for the emerging market economy), while the dashed lines have the same profile on carbon prices and a moderate rise in investment and subsidies, in line with International Energy Agency estimates.

Figure 1.6. Annual Investment Needs for Climate Adaptation and Sustainable Development Goals, 2021–40
(Percent of GDP)



Sources: Aligishiev, Bellon, and Massetti 2022; and IMF staff estimates based on IMF's SDG Financing Tool.
Note: The figure shows the investment needs across country groups related to additional climate adaptation needs and, for countries that have not done so, achieving the Sustainable Development Goals (SDGs). Lines indicate the minimum and maximum total investment needs. SDGs are assumed to be met by 2040 by spending a constant fraction of GDP each year. Additional climate adaptation needs refer to needs to build resilience. "SDS+" consists of developing small states as well as countries that have adaptation needs larger than 2.5 percent of GDP for 2021–30. EMs = emerging markets; LIDCs = low-income developing countries.

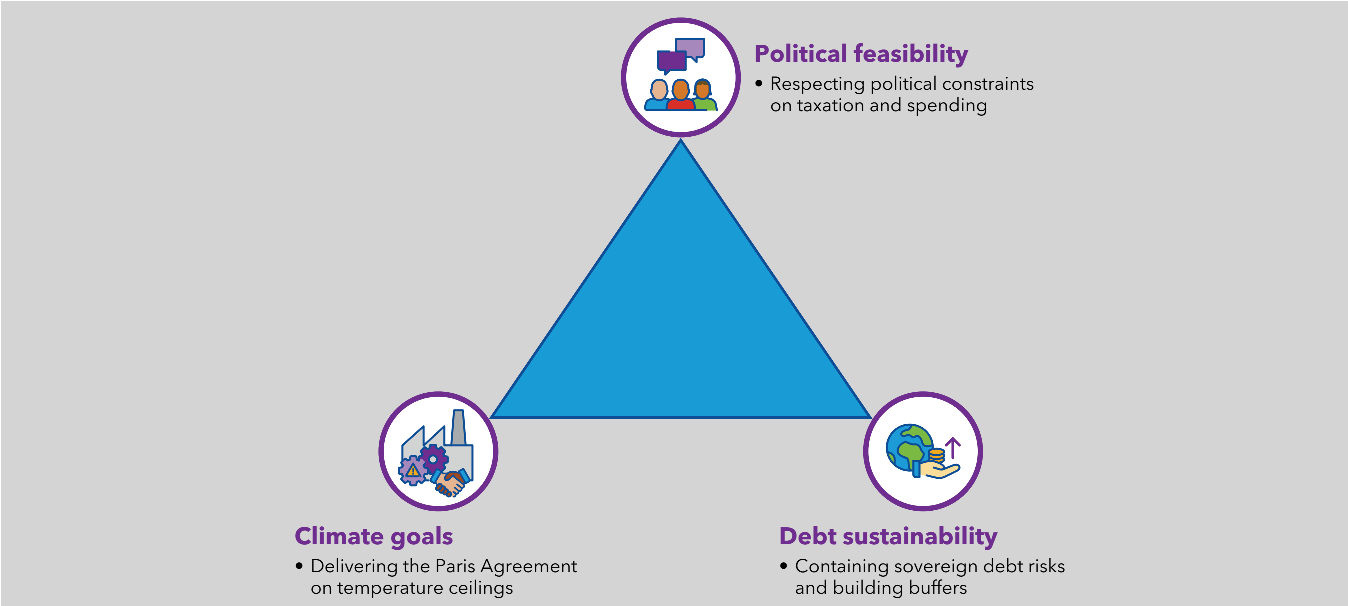
The key priority for emerging market and developing economies is growth and development. This already entails significant challenges with respect to public finances regarding raising tax capacity and enhancing the spending efficiency (Benitez and others 2023; Budina and others 2023). The green transition would entail additional fiscal costs, especially if they rely on expenditure-based measures. A comparable simulation for a representative large emerging market economy considers a cap on carbon prices at $45 a ton during 2030–50, together with a substantial increase in green investment and subsidies to reach net zero goals by 2060. Results of the simulation show that such a package would lead to an unsustainable surge in the debt-to-GDP ratio of more than 50 percentage points by 2050 (solid red line in Figure 1.5), with an associated sharp rise in borrowing costs. In the scenario with a more moderate increase in spending, emissions will only fall by 10 percent from current levels and will not be sufficient to achieve the net zero target (dashed red line in Figure 1.5).

Beyond investment in mitigation, many emerging market and developing economies need to build resilience and adapt to climate change. This is particularly the case for small developing states, which have the largest needs for climate adaptation, at an average 2.7 percent of GDP a year until 2030, in addition to their already-sizable needs for investment to meet other Sustainable Development Goals (Figure 1.6). Many low-income countries have no fiscal space, despite large needs in adaptation and relatively low-cost opportunities for abatement.

Fossil fuel-producing countries face a distinct fiscal challenge, as commodity revenues will decline markedly if the global economy pursues a path toward net zero emissions. Mesa Puyo and others (2023) estimate that for a group of 27 fossil fuel producers, fiscal revenue will decline by 5.5 percent of GDP on average between 2019 and 2040. These countries also need to reduce domestic emissions including from extractive industries, possibly adding to fiscal costs. However, the scope for using extractive revenues to finance economic development is highly sensitive to the pace of global decarbonization efforts (Box 1.2).[5]

[5]The impact on fossil fuel revenues depends on the scenarios of global transition, which affect the demand and production of fossil fuels. A given path for global fossil fuel production could be consistent with different price paths, implying a wide range of possible revenue and economic outcomes for fossil fuel-producing countries.

Figure 1.7. Climate Crossroads—Tackling the Climate Change Trilemma



Source: IMF staff compilations.

These issues point to a fundamental trilemma for policymakers between achieving (1) climate goals, (2) fiscal sustainability, and (3) political feasibility (Figure 1.7). If governments rely mostly on expenditure measures, this approach can be politically feasible, but debt will rise substantially. But if they instead continue on the current emission paths with only moderate measures, they cannot achieve their climate goals. Carbon pricing can relax fiscal pressures but—similar to other revenue measures—can be politically unpopular despite its efficacy in reducing emissions and revenue-generating potential (Klennert and others 2018; Douenne and Fabre 2022). The only way to jointly achieve these three goals is through a carefully calibrated mix of policies that varies across countries and involves carbon pricing alongside other measures to address distributional concerns and cost-of-living impacts, elaborated in the following sections.

Designing Efficient and Fiscally Responsible Policies

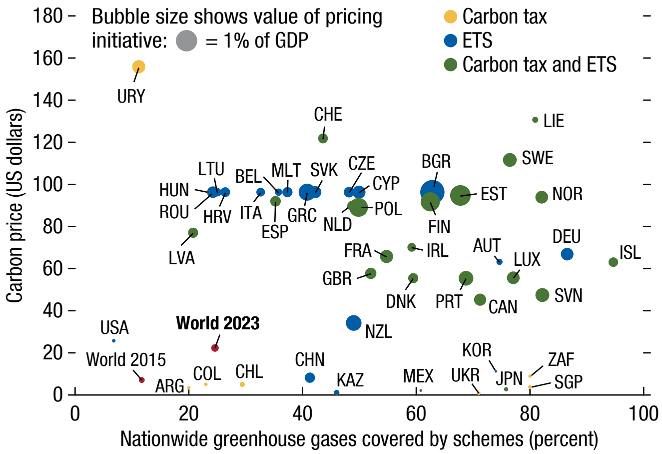
Governments need to design mitigation policy packages that effectively combine different instruments. This entails encouraging private sector behavioral shifts primarily through pricing mechanisms while accounting for (1) climate goals: choosing low-cost, efficient instruments for abatement to achieve emission reductions; (2) fiscal sustainability: exploiting scope for revenue mobilization; and (3) political feasibility. At the same time, the policy mix should include complementary measures to address market failures, for example, to facilitate investment, innovation, and technology deployment, as well as to address social, distributional, and political acceptability concerns. These instruments are elaborated in the following.

Economywide Mitigation Policies

Carbon pricing is necessary but not sufficient to reduce emissions (Nordhaus 2021). It is the principal economywide mitigation instrument and can take the form of a carbon tax or an emission trading system.[6]

[6]See the October 2019 *Fiscal Monitor* and Parry, Black, and Zhunussova (2022) for details on carbon taxes and emission trading systems. An example is the EU Emissions Trading System, which limits, via permits, emissions of specified pollutants from sectors such as power generation, energy-intensive manufacturing, and air transportation and allows firms to trade their emission permits (a "cap-and-trade scheme"). The cap for total EU-wide emissions tightens every year. Some firms are still receiving free allowances for certain emissions, but those allowances will be phased out by 2030. Emission trading systems typically require more involved administration and may not be practical in countries with small numbers of firms that do not have liquid trading in the market (Dechezleprêtre, Nachtigall, and Venmans 2018).

Figure 1.8. Explicit National, Subnational, and Regional Carbon-Pricing Schemes, 2022
(Carbon prices, US dollars)



Sources: National sources; World Bank, Carbon Pricing Dashboard; and IMF staff calculations.
Note: EU ETS includes *Iceland*, *Liechtenstein*, and *Norway*. Prices are weighted averages across schemes in a country. Country-specific values are calculated using sold auctions and average prices. *Mexico*'s subnational schemes and ETSs for *Indonesia* and *Montenegro* and are not included in the figure owing to lack of data. Data labels in the figure use International Organization for Standardization (ISO) country codes. ETS = emission trading system.

Economists find it to be the most efficient mitigation instrument, as it promotes the full range of behavioral responses to reduce energy use and shift to low-carbon fuels. It can also incentivize the private sector to innovate in and adopt new, low-carbon technologies, especially if a clear and credible rising price path is specified. Over the short to medium term, carbon pricing can raise substantial revenue, which can be used to finance other mitigation instruments and achieve broader economic and distributional objectives and thereby gain public support (Dabla-Norris and others 2023a; Dabla-Norris and others, forthcoming; Box 1.1). Carbon taxes are relatively easy to administer and can be integrated into existing procedures for collection of fuel taxes and extended to fossil fuels.

An increasing number of countries have adopted carbon pricing, suggesting that limited public support for carbon pricing is not a given. Carbon-pricing initiatives currently span 49 advanced and emerging market economies at various government levels, more than double the total one decade ago (Figure 1.8); at least 23 additional countries are planning to introduce carbon-pricing schemes, including *Kenya* as part of its efforts to achieve national emissions reduction targets (IMF 2023a). For example, *Sweden* successfully introduced a carbon tax in 1991 as part of a broader set of fiscal reforms that included cuts in corporate and personal taxes, alongside extensive social discussion to reinforce political trust and transparency. *Chile* introduced green taxes in 2014 as part of a broader tax reform package that also included increasing education and health care spending. The process included public consultations and commitment to present results periodically. *Singapore* introduced a carbon tax in 2019 and reduced policy uncertainty by announcing the scheduled tax path through 2030, with carbon revenues used to support decarbonization efforts and help businesses and households cope with the green transition.

That said, overcoming political hurdles is challenging, making it difficult to raise carbon prices significantly or expand coverage to broader economic activity. Even if governments can overcome the negative perceptions, carbon-pricing schemes alone will be insufficient to enable countries to achieve their climate goals. For instance, carbon pricing alone will not suffice in reducing emissions in hard-to-abate sectors such as buildings, which require stronger incentives to retrofit old structures (for example, with electric heat pumps) to cut consumption of fossil fuel-based energy.[7] Hence, carbon pricing is a necessary part of the policy mix but requires additional sectoral and other complementary policies.

In many countries, fuel excises provide an important source of fiscal revenues, generating between ½ and 1½ percent of GDP a year (de Mooij and others 2023). Over the medium to long term, however, those excises will decline as the carbon footprint of economies shrinks, requiring governments to collect alternative revenues to offset the loss, such as charges on vehicles per kilometer traveled (Online Annex 1.3). Elsewhere, countries still subsidize fossil fuels, sometimes at a high cost to government. Phasing them out provides opportunities to mitigate climate externalities and reduce fiscal costs.[8]

[7]Providing incentives for insulation and other retrofitting and for adopting energy-efficient appliances may require public support and could entail sizeable fiscal costs (UK Office of Budget Responsibility 2021; UNCTAD 2022a; Pisani-Ferry and Mahfouz 2023).

[8]According to Black and others (2023a), explicit fossil fuel price subsidies were $1.3 trillion (1.3 percent of global GDP) in 2022. However, the absence of a price for the environmental damages from global warming, local air pollution, and traffic congestion adds another implicit subsidy on fossil fuels. Including all those social costs yields a staggering $7 trillion (7.1 percent of global GDP) of total subsidies on fossil fuels.

Table 1.1. Comparison of Mitigation Instruments

Mitigation Instruments		Desirability and Feasibility				Environmental Effectiveness by Sector						
Coverage	Instrument	Economic Efficiency	Revenue Mobilization	Administrative Practicality	Political Acceptability	Power	Industry	Transport	Buildings	Forestry/ Land Use	Extractives (CH_4)	Livestock (CH_4, NO_x)
Economywide policies	Carbon taxes	Dark green	Dark green	Dark green	Red	✓✓✓	✓✓✓	✓✓	✓✓	✓	✓✓✓	✓✓✓
Economywide policies	Emission trading systems	Dark green	Light green	Red	Yellow	✓✓✓	✓✓✓	✓✓	✓✓	✓	✓✓	✓✓
Sectoral policies	Feebates (fees/rebates for dirty/clean firms/ products/activities)	Light green	Yellow	Yellow	Light green	✓✓	✓✓	✓✓✓	✓✓	✓✓	✓✓	✓✓
Sectoral policies	Tradable performance standards	Light green	Yellow	Red	Light green	✓✓	✓✓	✓✓			✓	✓
Sectoral policies	Green subsidies	Light green	Red	Yellow	Dark green	✓✓	✓✓	✓✓	✓	✓	✓	✓
Sectoral policies	Requirements for green technologies/ activities	Red	Yellow	Yellow	Yellow	✓	✓	✓✓	✓✓	✓	✓	✓

Complementary policies					
Issue	Network externalities for clean technologies	Innovation market failures	Burdens on households	Burdens on firms
Instruments	Public investments	R&D incentives, timebound technology subsidies	Targeted assistance, equitable revenue use	Output-based rebates, tax relief, border adjustments

Color scale (dark green → light green → yellow → red): Declining efficiency/revenues/practicality/acceptability

✓ = Somewhat environmentally effective
✓✓ = Effective
✓✓✓ = Very effective

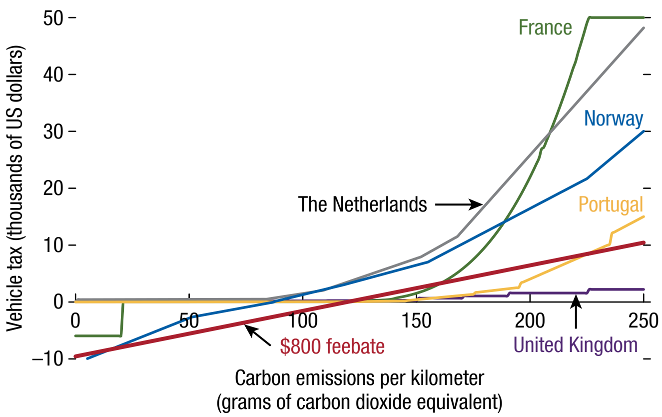
Source: IMF staff compilation.
Note: Environmental effectiveness reflects the extent to which policies exploit various potential behavioral responses for reducing emissions within a sector (based on economic theory and model simulations). CH_4 = methane; NO_x = nitrogen oxides; R&D = research and development.

Sectoral Mitigation Policies

Sectoral mitigation instruments complement carbon pricing in important ways. Depending on their design, they are generally politically acceptable, can promote a broad range of behavioral responses from households and firms for cutting emissions, and address certain market failures or externalities. Common sectoral mitigation instruments include the following (also see Table 1.1).

- *Feebates* involve a sliding scale of fees associated with (and rebates on) products or activities with emission rates above (below) a specified pivot point whereby energy efficient practices are rewarded. They encourage a decline in emission intensity in a particular sector, although they do not promote full behavioral responses. For example, feebates encourage people to buy electric or fuel-efficient vehicles, but they do not encourage people to drive less. They are revenue neutral if the pivot point is aligned with average emission rates and updated over time. European countries have increasingly integrated them into vehicle taxation—often with very high implicit carbon prices—promoting a rapid shift to electric vehicles in countries like *The Netherlands* and *Norway* (Figure 1.9). Feebates can also be applied to other sectors, although new administrative and technical capacity to monitor emissions is needed (Online Annex 1.4). Feebates usually have greater public support than carbon pricing, as they do not impose additional costs on the average household or firm.
- *Tradable performance standards* also provide broad incentives to reduce emission intensity. For example, firms are often required to meet a standard for average carbon emissions per kilowatt-hour across power generation plants or per ton of steel. Those that fall short of the standard can purchase credits from other firms that exceed the standard. Although such standards are usually politically acceptable, they do not raise significant fiscal revenue and require fluid markets for trading credits; thus, they are less practical for some sectors, such as forestry and residential buildings. *Canada* has a federal backstop program that includes an output-based pricing system for its industrial sector that concentrates taxation on large emitters to minimize

Figure 1.9. Effects of Feebates for New Vehicles, 2021



Sources: European Automobile Manufacturers' Association; and IMF staff estimates.

competitiveness and carbon leakage risks.[9] *China*'s tradable performance standard for the power sector, or intensity-based emission trading system, includes a benchmark on the maximum emissions per electricity generated.

- *Green subsidies* aim to overcome market failures and externalities related to the development, deployment, and adoption of low-carbon technologies.[10] Although subsidies are generally considered undesirable from an economic standpoint because of potential distortions, the urgent need for rapid global decarbonization, including through technological innovations, can justify their use to address market failures and other externalities common in climate change. For example, subsidies for research and development can overcome underinvestment by private firms in critical technologies. Deployment subsidies can help firms exploit economies of scale to speed up the use of established low-carbon technologies. For instance, as part of reforms enacted in 2014–16, *Egypt* provided incentives to invest in and operate renewable power projects and sell electricity via long-term power purchase agreements to stabilize electricity prices (known as a "feed-in subsidy"). Under its Contracts for Difference scheme, the *United Kingdom* offers subsidies for large-scale renewable energy projects, which gives private electricity generators greater certainty and reduces exposures to volatile wholesale prices. However, subsidies promote only limited mitigation responses. For example, subsidies for wind and solar generation only favor their use; they do not encourage a broad shift toward sources of less-polluting energy, such as from coal to gas or to other renewables. While subsidies often have strong domestic political appeal, they entail large fiscal costs and can generate negative spillovers, raising cross-border competitiveness concerns if not carefully designed or coordinated (Kammer 2023).[11]
- *Regulation or minimum standards.* Another type of sectoral policy involves regulations or requirements such as minimum shares of renewable use for power generators or minimum shares of electric vehicles in vehicle sales fleets. For instance, since 2023, *Colombia* has required power utilities to procure at least 10 percent of the electricity sold to end users from renewable energy sources. Regulations promote only narrow behavioral shifts, however. For example, requirements regarding shares of electric vehicles in vehicle sales do not promote shifts to more efficient internal combustion engine vehicles. Regulations are also unlikely to generate fiscal revenue and can be costly for firms to comply with, particularly small and medium-sized enterprises. Regulations can be made more flexible and cost-effective by allowing firms to pay a fee or purchase credits that exceed their requirements. While the public usually supports these measures, they can often be difficult to administer, as multiple entities are involved.

Complementary Policies

Complementary policies to address market failures, support private sector efforts, and ease burdens on households and firms can play a role in improving the public perception and political feasibility of mitigation policies. These policies are not substitutes for economywide and sectoral mitigation policies but can improve their effectiveness.

[9]The federal backstop does not apply in all provinces as some have opted for their own carbon pricing policy design.

[10]Subsidies are sometimes part of government efforts to promote low-carbon technologies through measures targeted toward specific domestic firms, industries, sectors, or regions to promote domestic innovation, adoption, and production, generally referred to as "green industrial policies."

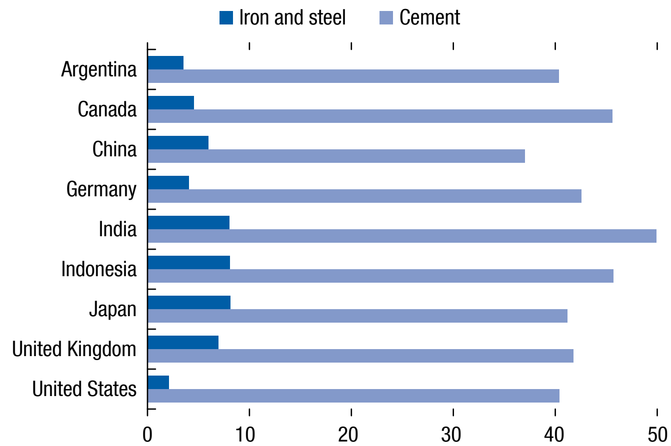
[11]Subsidies tend to be generally politically acceptable because, while their benefits are typically well understood, their costs in terms of higher taxes or lower spending elsewhere tend to be less salient to the public (Dabla-Norris and others 2023b).

Public investment. With the right mix of policies, the private sector will fund most clean investments for decarbonization. However, some large-scale investments—such as pipelines for clean hydrogen and carbon capture and storage, high-voltage transmission lines to link different plants using renewables to generate electricity, or charging stations for electric vehicles—could be undersupplied if left entirely to the market. At the global level, the required additional public investment (new green investment on clean technologies of 0.4 percent of GDP net of the decline in fossil fuel investment of 0.1 percent of GDP) is estimated at about 0.3 percent of GDP a year, on average, with the upfront capital costs concentrated over the next 20 years and declining thereafter (IEA 2021; IMF 2021). Governments can undertake green public investment to complement private capital. For example, the *United States* National Electric Vehicle Infrastructure Program provides $5 billion over five years to expand infrastructure for charging electric vehicles and establishing an interconnected national network. *India* has launched several initiatives regarding such infrastructure, notably the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles scheme.

Transfers. Climate measures such as phasing out fossil fuel subsidies and higher carbon prices will raise energy prices and, indirectly, the prices of other goods that use energy as an input. Governments can compensate households for the resulting impact by using a portion of the revenue from carbon-pricing schemes for targeted transfers to households, social safety nets, or lowering other taxes. Unemployment insurance coupled with active labor market policies could support workers in regions severely affected (Coady, Parry, and Shang 2018; October 2019 *Fiscal Monitor*). *Oman*, for example, started to phase out electricity subsidies in 2021 while protecting low-income households. *Indonesia*'s fuel reform in 2016 included targeted support for poor households, which was linked to its social assistance program.

Competitiveness. Unilateral pursuit of climate policies can raise cross-border competitiveness concerns. For example, production costs for energy-intensive, trade-exposed industries covered by carbon-pricing schemes would increase because of the associated costs to adopt emission reduction measures as well as from higher electricity costs. To avoid these costs, industries could relocate to other countries with less stringent emission standards or carbon pricing.

Figure 1.10. Change in Domestic Iron and Steel and Cement Production Costs from Baseline, 2030
(Percent)



Source: IMF staff estimates using the IMF–World Bank Climate Policy Assessment Tool.
Note: The pricing policy depicted in the figure imposes charges of $50 a ton of carbon dioxide. Production cost increases include mitigation costs and charges on unabated emissions.

Using the IMF–World Bank Climate Policy Assessment Tool, Figure 1.10 illustrates direct production cost increases, relative to baseline production costs, for iron and steel and cement under a unilaterally imposed carbon tax of $50 a ton in 2030. Production costs increase by about 5–10 percent for iron and steel but by a more substantial 35–50 percent for cement. Changes in sectoral emissions arising from moving production to countries with laxer emission standards (carbon leakage) are estimated at 10–30 percent, under plausible assumptions regarding production cost increases, pass-through into domestic consumer prices, and the cost of relocation (Parry and others 2023). These effects are small, however, relative to the economywide reductions in emissions that the tax achieves. Border carbon adjustments, in which a fee is charged on carbon embodied in imported products, possibly matched by rebates for exports to restore a level playing field for domestic and foreign firms, can mitigate these competitiveness concerns.[12]

[12]The *European Union* is phasing in a border carbon adjustment mechanism involving charges on imported aluminum, cement, steel, fertilizers, and electricity. It is also phasing out free allowance allocations under its Emission Trading System for domestic producers in the industries that produce these products. See Parry and others (2021) and Keen, Parry, and Roaf (2021) for a discussion of the economic and legal aspects of border carbon adjustments.

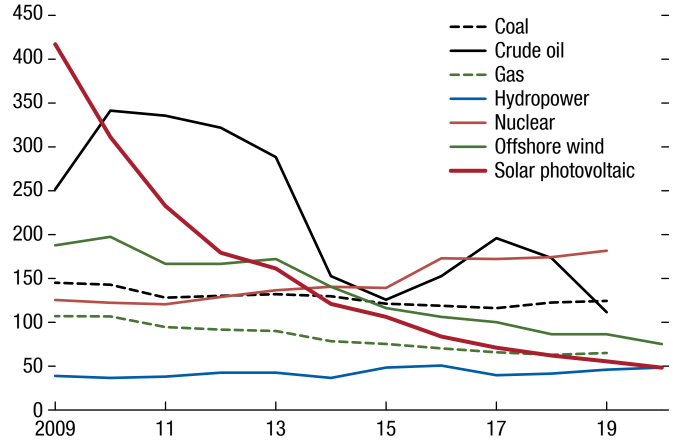
However, such adjustments need to account for carbon pricing in trading partners, limit administrative burdens, and avoid violating World Trade Organization rules.

Promoting Technology Diffusion and Innovation

Technological innovation and deployment of low-carbon technologies will play a key role in achieving global climate mitigation goals. Overcoming obstacles to diffusion is crucial, as many technologies for emission reductions already exist. According to the International Energy Agency (2020, 2022a), use of known and commercially proven technologies can achieve about 90 percent of the emission reductions necessary to achieve climate goals by 2030. The cost of many of these technologies has already decreased significantly during recent years (Figure 1.11). Solar power has become the most affordable renewable source of electricity—even cheaper than fossil fuels—thanks to modular production, installation efficiency, economies of scale, learning-by-doing effects, and government support from various countries (IEA 2020b; see Online Annex 1.5). However, financing and capacity limitations hinder the adoption of clean frontier technologies in emerging market and developing economies (UNCTAD 2022b; Capelle, Pierri, and Bauer 2023). Moreover, government policies and network infrastructure can play a vital role in the adoption and deployment of low-carbon technologies. For instance, renewables require electricity markets with low regulatory barriers to encourage private sector participation, while the electrification of energy end use in transportation, industry, and buildings requires upgraded grid technologies.

In the medium to long term, new technologies will be necessary, including those that are currently in the early stages and not yet commercially available. For instance, carbon capture and storage is still in its infancy—even though efforts to accelerate adoption have been ongoing for decades. A key challenge for technology adoption is that firms pioneering the technology may not fully capture the spillover benefits that other firms imitating the technology could gain by leveraging the knowledge or benefiting from the learning-by-doing experiences. Fiscal interventions are thus likely needed, including through public research and development, as well as incentives for private research and development through patents, research subsidies, tax incentives, prizes, or some combination of these.[13] However, these incentives need to be carefully designed.

Figure 1.11. Learning Curves for Power Generation, by Technologies
(US dollars per megawatt-hour)



Sources: IRENA 2022; Way and others 2022; and Ziegler and Trancik 2021a, 2021b.
Note: The figure shows the levelized cost of electricity: The average net present cost of electricity generation over the lifetime of the generator.

An increasing number of countries are adopting policies to promote domestic innovation, adoption, and production of low-carbon technologies, such as subsidies and tax incentives for specific domestic firms, industries, sectors, or regions. Such policies will need to be time bound, transparently presented in budgets under a strong governance framework, and complemented with carbon pricing. They should not violate the legal obligations imposed by trade agreements; international coordination is required to minimize adverse spillovers. When implemented in accordance with these principles, such policies could accelerate decarbonization. However, uncoordinated actions pose significant risks by distorting trade and investment flows and could give rise to competitiveness concerns and a "subsidy race" that harms developing countries (Cherif and others 2022; IMF, forthcoming). Other instruments such as government credit guarantees and public-private partnerships, often

[13]In principle, with a robust and efficient price for carbon emissions, additional incentives for development of clean technology should be similar to those for general research and development. Additional treatment can be warranted if the appropriability problem is more severe for clean technologies than for other technologies. This may be plausible in regard to technologies that are currently far from the market (for example, green hydrogen–based energy).

carry fiscal risks and need to be monitored closely under strong institutional frameworks (Battersby and others 2022).

Technology transfer and stronger institutions are conducive to technology absorption. They require robust legal and regulatory frameworks, transparent governance, property rights enforcement, and fair competition (Kiessling 2007; Manca 2009; Budina and others 2023). Moreover, enhancing development of human capital and investment in information and communications technology and other infrastructure can effectively harness the benefits.

Debt Impact of Climate Policy Packages

This section considers a policy package that achieves net zero emissions by midcentury. The package combines revenue and expenditure measures, including carbon pricing (to reduce emissions efficiently and generate fiscal revenues), green public investment (to complement green private capital), green subsidies (to encourage innovation and deployment of clean energy), and targeted transfers (to mitigate adverse impacts on households during the green transition). In this scenario, the private sector is expected to fund the majority of investment for decarbonization. The analysis operationalizes the net-zero-emissions target as an 80 percent reduction in 2023 emission levels by 2050 for advanced economies and by 2060 for emerging market economies, with the assumption that carbon capture and storage will offset the remaining emissions (IMF 2021; Black and others 2022a).

Using the same dynamic general equilibrium model as in "Are Current Policies Scalable on the Road to Net Zero?" this section simulates the effects of this policy package on debt dynamics for a representative advanced economy and emerging market economy. The effects of the policy package also depend on how fiscal instruments affect growth and interest rates. For instance, carbon pricing will increase government revenues but reduce near-term output. Expenditure measures will support output in the short term, while higher public capital will add to the economies' productive capacity, boosting long-term output. However, higher expenditures raise budget deficits and add to the pressures on interest rates and government borrowing costs by raising the demand for capital (macroeconomic channel) and increasing the supply of government debt (fiscal channel). The balance between carbon-pricing and expenditure measures in the overall package, as well as the endogenous effects on output and interest rates, determine the debt dynamics between today and 2050.

Advanced Economies

For a representative advanced economy calibrated to the average of data for Group of Seven economies, the simulated policy package requires an ambitious increase in carbon pricing, with the price reaching \$130 a ton by 2030 and \$235 a ton by 2050.[14] Despite rising carbon prices, revenues from carbon sources are projected to peak in about 2030, as decarbonization gradually erodes the carbon tax base. Hence, despite increasing carbon prices, carbon revenues as a share of GDP decline during 2030–50. On the expenditure side, the simulations assume a combination of an increase in green public investment and front-loaded green subsidies equivalent to about ½ percent of GDP, and transfers equivalent to 30 percent of carbon revenue (Känzig 2023).

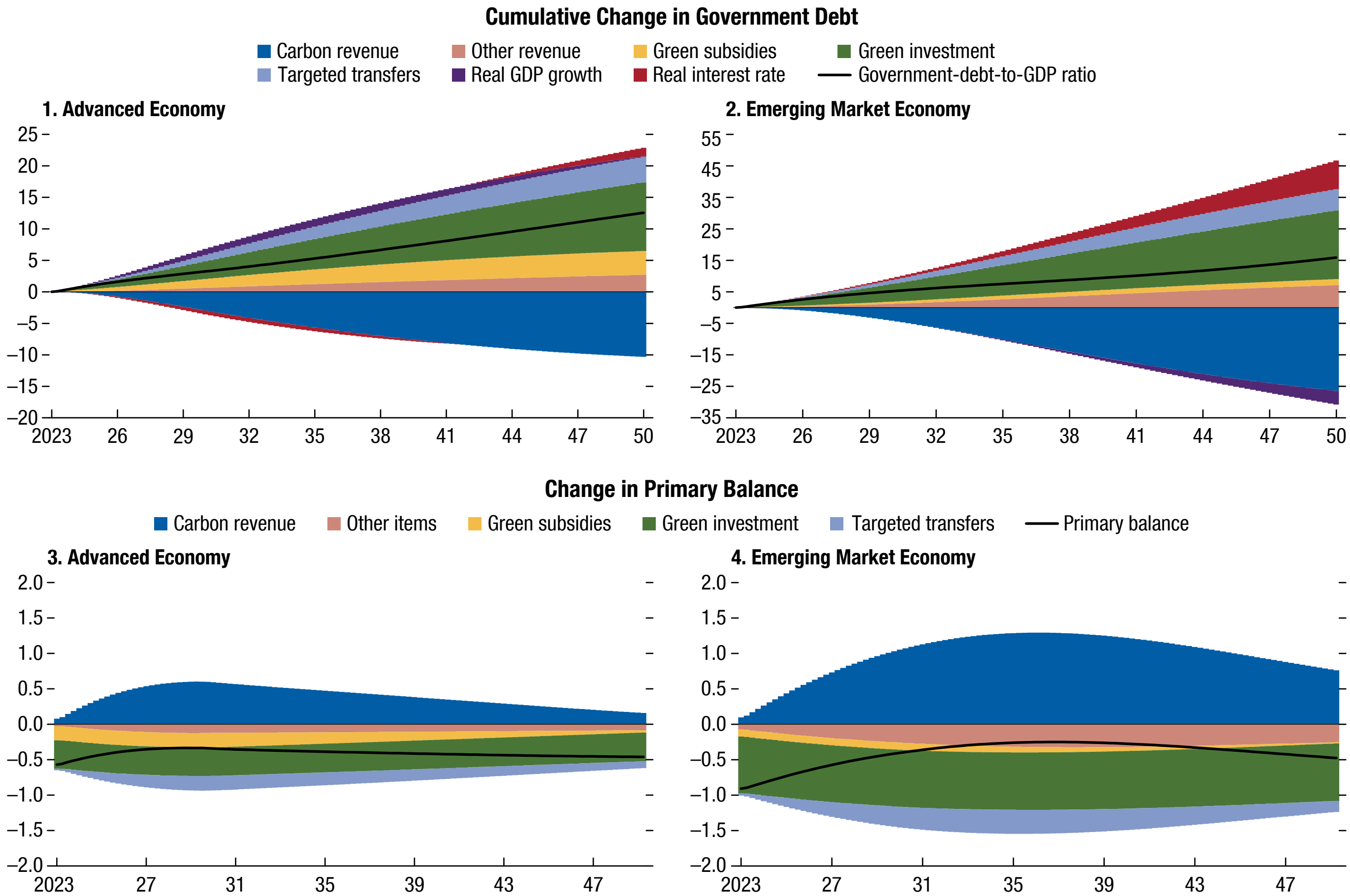
On balance, the debt-to-GDP ratio in this representative advanced economy increases by 10–15 percentage points by 2050, with the primary deficit rising moderately, by 0.4 percent of GDP a year, relative to the "business-as-usual" baseline in this scenario (Figure 1.12, panels 1 and 3) (Online Annex 1.2). Interest rate effects would be relatively muted because government debt would rise moderately, and lower demand for capital in brown sectors would partly offset the higher demand for capital in the green sector. Some advanced economies may have fiscal space to pursue such a combination of fiscal policies to meet the net-zero-emissions goal while maintaining debt sustainability. Countries can also raise revenues from other taxes or reduce other spending to contain the rise in debt.

Emerging Market and Developing Economies

A similar simulation is conducted for a representative large emerging market economy but with several differences compared to the representative advanced economy. First, most emerging markets currently have a lower share of

[14]The carbon prices are in line with the net-zero-emission scenario in IEA (2021). A price of \$235 a ton by 2050 is lower than the \$280 a ton by 2050 that would be necessary to achieve net zero emissions if carbon pricing were the only instrument used.

Figure 1.12. Implications of Net-Zero-Policy Packages on Debt and Primary Balance, Relative to "Business-as-Usual" Baseline, by Fiscal Component
(Percent of GDP)



Source: IMF staff simulations.
Note: For advanced economies, parameters and fiscal instruments are calibrated to a representative large advanced economy (that represents the average of data for Group of Seven economies). The policy package is designed to achieve net zero emissions in 2050. The value for public investment is consistent with the upper range of estimates by the International Energy Agency (2022b). Green subsidies are assumed to be front loaded and phased out after 2030, and targeted transfers are assumed to be proportional (at 30 percent) to carbon revenues. Given later emission peaks in emerging market economies, the policy package for those economies is designed to achieve net zero emissions by 2060. "Other revenue" includes taxes from capital, labor, and consumption, which vary owing to endogenous effects from macroeconomic variables even though tax rates are held the same. Parameters and fiscal instruments are calibrated to a representative emerging market economy that is assumed to reflect the weighted average of data for *Argentina*, *Brazil*, *China*, *India*, *Indonesia*, *Mexico*, *South Africa*, and *Türkiye*. The value for public investment is consistent with the upper range of International Energy Agency estimates for emerging market economies. For details, see Online Annex 1.2.

green energy than advanced economies and will have a lower carbon price during the initial phase of decarbonization—assumed in the simulation to reach $45 a ton by 2030, gradually rising to $150 a ton by 2050. Yet this lower carbon price yields greater carbon revenue than the case in an advanced economy for a longer period and leads to a later peak in emissions and carbon revenue (Figure 1.12, panels 2 and 4).[15] Second, green investment needs in emerging market economies are larger (at ¾ percent of GDP per year), owing to different ownership structures and less private investment in mitigation, consistent with International Energy Agency (2022b) estimates. Third, emerging market economies also face a higher risk premium—that is, greater sensitivity of borrowing costs to rising debt levels. Transfers to vulnerable households are assumed to be 30 percent of carbon revenue, the same as the scenario for advanced economies.

Incorporating these distinctive features and specific assumptions, the model simulation of this

[15]The simulations are based on *effective* carbon prices and so implicitly capture the effect of removing fossil fuel subsidies.

illustrative scenario suggests that public debt would increase by about 15 percent of GDP by 2050 in these economies relative to the "business-as-usual" baseline, equivalent to a rise in primary deficits by 0.4 percentage point of GDP a year on average (Figure 1.12, panel 4). The simulated rise in debt is subject to a wide range of 8–25 percent of GDP by 2050, depending on public investment, subsidies, and targeted transfers, as well as whether countries are fossil fuel producers (see alternative scenarios in Online Annex 1.2).[16] While the increase in debt-to-GDP ratio is comparable to advanced economies, the composition is different, with larger contributions from interest costs and higher public investment needs, while carbon revenues are higher.

Many emerging market economies would find the increases in debt and deficits challenging, especially those already experiencing high debt, as rising borrowing costs lead to higher interest payments and account for a sizable part of the deteriorating debt dynamics. As a result, they would be unable to afford a large redistribution of carbon revenues or meet their public investment needs. These call for improving spending efficiency and mobilizing alternative sources of finance, including other domestic tax revenues (Benitez and others 2023), and a greater role for private financing. A well-calibrated fiscal strategy could crowd-in private investment and financing to jumpstart growth, critical for emerging markets with limited fiscal space. Low-income developing countries should prioritize reducing energy intensity and adapting to climate change, given limited access to financing and modest contributions to global emissions. Reconciling climate challenges with growth and development needs in emerging market and developing economies therefore calls for efforts to mobilize domestic revenues and global financial support. For example, the IMF Resilience and Sustainability Trust provides long-term financing—which augments fiscal space and financial buffers—to strengthen economic resilience and support reforms that reduce risks associated with longer-term structural challenges, including climate change. The involvement of multilateral development banks plays a role to leverage private investment and provide risk-absorption capacity (October 2022 *Global Financial Stability Report*, Chapter 2). Moreover, knowledge transfers and deployment of established low-carbon technologies in these economies will be critical to raising productivity, crowding in private sector investment, and reducing overall fiscal costs (Online Annex 1.2).

[16]Fiscal costs will vary depending on the mix of revenue and spending policies. Sensitivity analysis shows that if government transfers are 50 percent of the revenue from carbon taxes, debt would rise by 25 percentage points of GDP by 2050, with an increase in primary deficits of 0.6 percentage point of GDP a year on average. If instead public mitigation investment and subsidy is reduced by about ¼ percent of GDP per year, debt would increase by 8 percentage points of GDP. Alternatively, if climate policies primarily rely on carbon pricing (higher than the baseline) with modest public investment of ¼ percent of GDP per year with no subsidy spending, the resulting carbon revenues can more than offset the investment spending and related transfers to households, leading to a small primary surplus, especially during the peak of carbon revenue (see Online Annex 1.2).

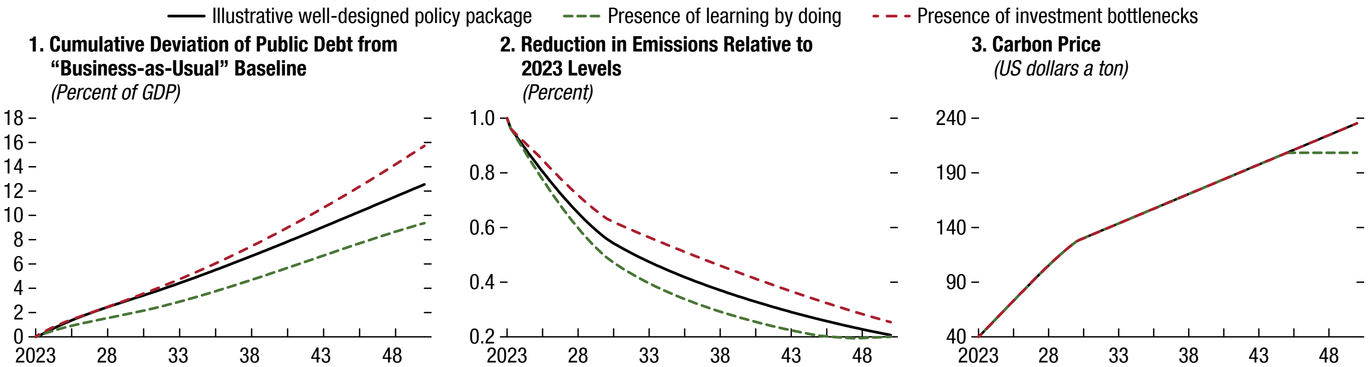
Technology Spillovers and Investment Bottlenecks

The effectiveness of green subsidies will depend on how firms respond to fiscal incentives and how easily they can shift to, or invest in, low-carbon technologies. Model simulations show that green subsidies will be more effective if learning-by-doing effects in clean technologies are present, allowing a faster reduction in emissions and limiting the associated output costs, while keeping public debt contained (dashed green line in Figure 1.13). However, bottlenecks to green investment, such as limited institutional capacities and disruptions in supply chains for critical minerals because of geoeconomic fragmentation (October 2023 *World Economic Outlook*, Chapter 3), could limit the potential for rapid uptake of green technology. Stranded assets in brown sectors—assets that need to be written down prior to the end of their economic life, such as old coal plants—could also be costly to divest or phase out. Such bottlenecks, if they take the form of adjustment costs imposed on investment, would slow the shift toward renewable energy, making green subsidies less effective and causing debt-to-GDP ratios to rise further (dashed red line in Figure 1.13). This also implies that emission targets may not be reached unless more forceful action through other measures, such as higher carbon prices, is taken.

The model is next used to explore different assumptions and policy packages. This exploration provides several key lessons in respect to policy design:

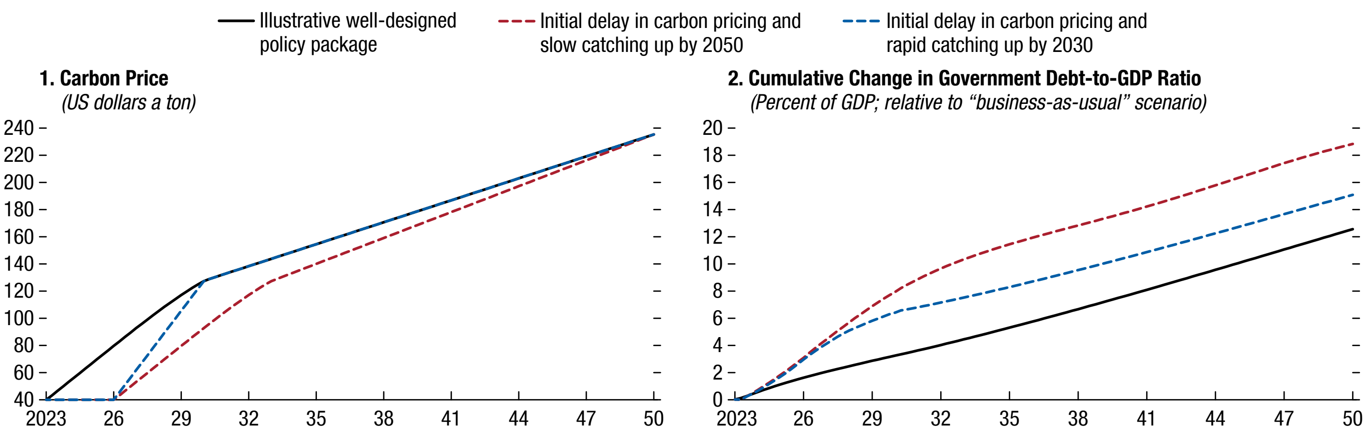
- *Delaying action on carbon pricing is costly.* Each year of delay in raising carbon prices is found to increase public debt by 0.8–2.0 percentage points of GDP in advanced economies, depending on how quickly carbon prices adjust after the initial delays and

Figure 1.13. Impact of Technology Spillovers and Investment Bottlenecks on Debt Dynamics



Source: IMF staff simulations.
Note: The figure assumes carbon prices are the same across scenarios before reaching net-zero-emission goals and is calibrated to a representative advanced economy (that reflects the average of the data for Group of Seven economies). When learning by doing is present, a 1 percent increase in energy capital is assumed to raise total factor productivity by 0.1 percent in the energy sector, in accordance with Chang, Gomes, and Schorfheide (2002) and Dietz and Stern (2015).

Figure 1.14. Costs of Delay in Raising Carbon Prices



Source: IMF staff estimates.
Note: The scenario depicted in the figure assumes a three-year delay (from 2023 to 2026) in raising carbon prices relative to the illustrative well-designed policy package for the representative advanced economy in the chapter text.

assuming that spending-based policies are scaled up to deliver the same level of emission reductions by 2050 (Figure 1.14; Online Annex 1.2). Although carbon revenues are projected to peak later for emerging market economies, delays would still increase debt in a notable way (about 0.9 percentage point of GDP), even when carbon prices catch up quickly following the initial delay. The longer countries wait to make the shift to a greener future, the costs will likely be larger (October 2022 *World Economic Outlook*, Chapter 3).

- *Policy sequencing matters.* Although public debt would likely increase during the green transition, combining fiscal instruments strategically can limit the rise in debt. For instance, the initial rise in carbon tax revenues could be timed to coincide with front-loaded expenditures on green subsidies, containing the impact on deficits. Delaying carbon revenues until after emissions have peaked will decrease the revenue base and widen fiscal deficits in the interim.
- *Accounting for technology spillovers and addressing investment bottlenecks is critical.* The presence of externalities or spillovers can increase the effectiveness of green subsidies, enabling lower decarbonization cost. At the same time, addressing bottlenecks, such as reducing trade frictions or diversifying supply chains, will allow firms to shift swiftly toward clean energy. At the international level, augmenting international climate finance

can facilitate trade in low-carbon technologies and their components and scaling up of technology transfer (IMF 2021).

- *Catalyzing private climate finance will help decarbonization.* Existing commercially proven technologies have potential to promote decarbonization. Policies that price carbon or otherwise incentivize these technologies help catalyze private climate finance and accelerate the shift toward clean energy and technologies. Catalyzing private climate finance can take many forms, including the use of subsidies, environmental regulations, and strengthening the climate information architecture (data, disclosure, and taxonomies), as well as public-private risk sharing through blended finance structures (October 2023 *Global Financial Stability Report*, Chapter 3). However, some instruments, such as government credit guarantees, can be associated with large fiscal risks.
- *Incorporating climate actions in debt sustainability analysis is essential.* Projected debt levels show considerable uncertainty, depending on the size of investment needs, assumptions about the elasticity of substitution between energy sources, the economic impact of fiscal policies, and the degree to which firms and households take up different tax credits and subsidies (Online Annex 1.2). In addition, the effects of global warming on economies are also subject to considerable uncertainty. Some mitigation policy packages for emerging market economies may turn out to be less affordable than others, which will require further mobilizing domestic tax revenues and incentivizing greater private financing. The uncertainty about the path that debt will take highlights the need to develop further tools to incorporate climate actions into debt sustainability analysis.[17]

[17]For example, the IMF Quantitative Climate Change Risk Assessment Fiscal Tool assesses the fiscal risks from long-term climate change by quantifying climate scenarios against a baseline (Harris and others 2022; Harris, Tim, and Rahman 2023). The IMF's Sustainable Development Goals–Climate tool integrates climate change and natural disaster risks into a dynamic growth model to assess the financing and debt trade-offs of policies in reaching Sustainable Development Goals (Bartolini and others 2023). Akanbi, Gbohoui, and Lam (2023) provide a tool in calibrating fiscal rules considering natural disaster risks. In addition, the IMF has made efforts to improve the availability of quality climate data to support decision making and foster public awareness, such as the IMF Climate Change Indicators Dashboard and related publication on *Data for a Greener World* (IMF 2023b) and IMF Data Standards Initiatives. The IMF continues to work toward enhancing the climate information architecture, collaborating with international standard setters and international financial institutions.

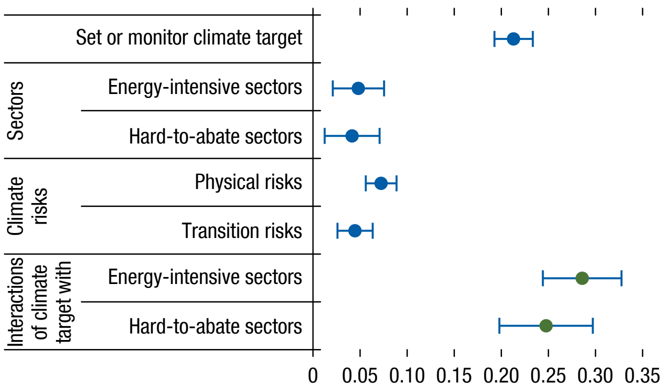
The effects of climate policies on debt dynamics also reflect the uneven impacts of such policies across age groups. Analysis based on an overlapping-generations model (Kotlikoff and others 2021) shows that mitigating the adverse impact of the green transition on current age cohorts through debt-financed transfers will impose higher taxes on future cohorts to finance future debt service (Online Annex 1.6). In contrast, if governments pursue a balanced-budget policy, each generation will bear the cost of contemporaneous climate change mitigation efforts. Current generations may be reluctant to advance climate mitigation, as they bear most of the costs, whereas future generations would suffer from worse climate outcomes arising from limited action today.

Rising public debt and scaled-up green public investment point to the need for strengthening fiscal frameworks and institutions to enhance spending efficiency and improving debt and investment management and practices (Online Annex 1.7). Green public financial management integrates climate considerations into existing budget processes. Existing frameworks can be adapted to prioritize and direct scarce resources to policies that respond to climate concerns. Public financial management should also promote transparency and accountability for the climate impact of fiscal policies. Moreover, governments need to ensure green public investment is routed through the usual budget channels. Alternative systems dedicated to green investments—such as extrabudgetary operations or provisions to exclude green investment in fiscal rules—run the risk of fragmenting the budget and fiscal decision making. While project-specific financing can attract private investors, earmarking public resources risks creating budget rigidities.

Facilitating Green Transition in Firms

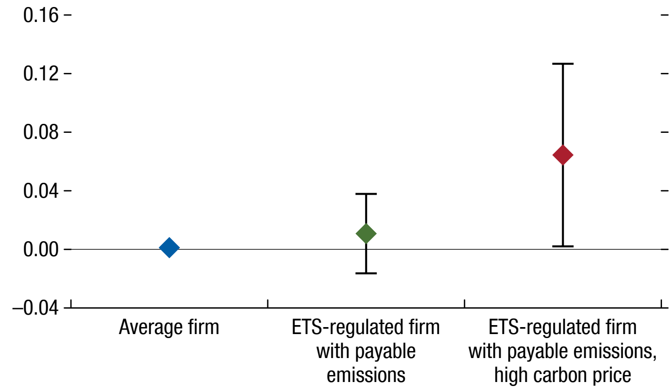
The green transition will require strong complementary actions on the part of public and private actors because—as discussed earlier in the chapter—firms will need to undertake the majority of decarbonization efforts, working in tandem with governments to shift toward clean energy and technologies. Regulatory measures and fiscal incentives can encourage firms to improve energy efficiency, reduce their energy use, or invest in or adopt low-carbon technologies. This section examines the impact of these policies on firms' climate investments and resilience to higher energy prices, strengthening the case for using a mix of

Figure 1.15. Likelihood of Investing in Mitigation: New, Less-Polluting Technology
(Coefficient estimates)



Sources: European Investment Bank Group Survey on Investment and Investment Finance 2022; and IMF staff estimates.
Note: The figure shows estimated coefficients obtained from a linear regression model that includes country fixed effects and robust standard errors (see Online Annex 1.8). The dependent variable is binary, based on firms' responses to a survey question on whether they are investing in new, less-polluting business areas and technologies to reduce their greenhouse gas emissions. Results are consistent with the findings of the 2023 *EIB Investment Report*. The whiskers indicate the 95 percent confidence interval for the estimated coefficients.

Figure 1.16. Environmental Policy Stringency and Changes in European Firms' Investment
(Coefficient estimates)



Sources: EU Emissions Trading System (ETS); European Investment Bank; IMF, World Economic Outlook database; Kalantzis and others, forthcoming; Orbis; and Organisation for Economic Co-operation and Development (OECD).
Note: The figure shows estimated coefficients obtained from a panel regression model for 12 European countries during 1995–2020 (see Online Annex 1.8). The dependent variable is changes in fixed assets (in logarithms) as a proxy for investment. Each coefficient estimate represents the impact of changes in the OECD's market-based Environmental Policy Stringency Index for the indicated sample of firms. "ETS-regulated firms" are those with regulated installations in the EU ETS. "Payable emissions" are the difference between verified emissions and free allowances. "High carbon price" refers to periods when EU carbon price exceeds 75th percentile. The whiskers indicate the 95 percent confidence interval for the estimated coefficients.

instruments, including carbon pricing, to facilitate decarbonization.

Regulations can enhance firm investment in low-carbon technologies. Analysis of a representative firm-level survey from the European Investment Bank[18] provides evidence that firms that set or monitor emissions, particularly those operating in energy-intensive or hard-to-abate sectors (which are often subject to government regulations or emission standards) are among the most likely to invest in new, less-polluting technologies or products (Figure 1.15; Online Annex 1.8).[19]

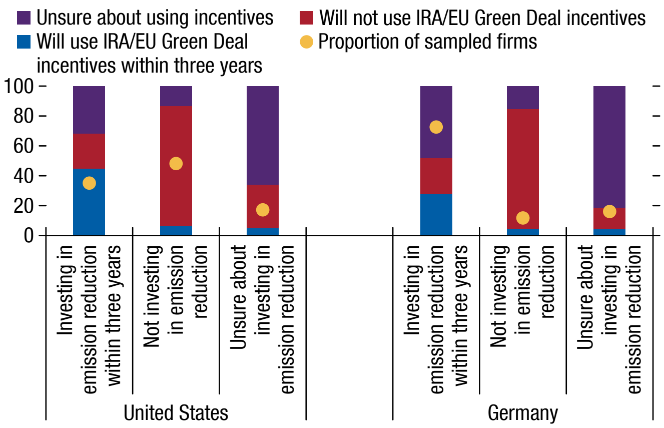
The stringency of regulatory policies associated with climate also affects the investment behavior of firms. To explore this, the analysis here examines firms regulated under the EU Emissions Trading System. It suggests that more stringent market-based policies that put a price on pollution, such as permit prices in carbon-trading schemes and taxes on greenhouse gas emissions, have a significant positive impact on the investment by firms regulated under the system, but only in periods of already-high carbon prices and when emissions exceed allowance levels (Figure 1.16). However, these regulations have no significant impact when emissions are within their free allowance levels. These findings suggest a reinforcing role between high carbon prices and market-based regulatory measures, in which stringent policies could provide incentives for investment by firms if they need to pay for emissions at high carbon prices (Online Annex 1.8).

An important question is whether firms are sufficiently resilient to respond to a rise in the cost of carbon-based energy. To assess firm responses to shocks to energy cost, this section explores how firms have responded to the energy price hike of 2022. Two surveys of firms in *Germany* and the *United States* (Online Annex 1.9) show that firm balance sheets have

[18]The European Investment Bank Group Survey on Investment and Investment Finance is a survey, administered by the European Investment Bank, covering all *European Union* 27 countries, the *United Kingdom* (until 2021), and the *United States* (since 2019), comprising approximately 13,000 firms annually. The survey is designed to be representative at the country level as well as sector and firm-size levels for most countries. For technical details, please see Brutscher and others (2020).

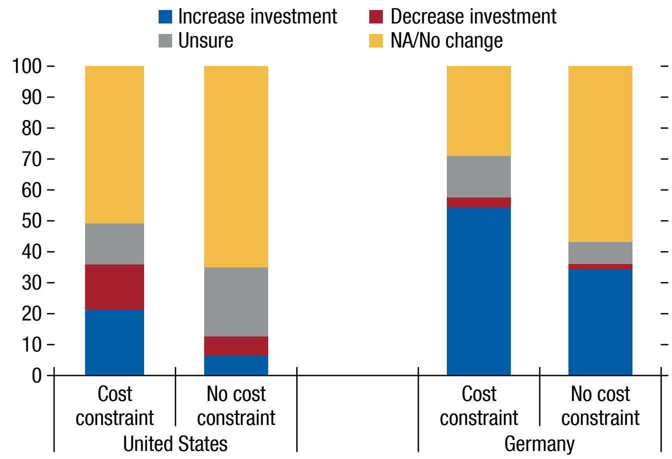
[19]While firm-level data cannot distinguish between mandatory and voluntary climate targets, the empirical result corroborates findings in existing literature that firm-level climate targets are positively correlated with investment in renewable energy and emission reduction (Ioannou, Li, and Serafeim 2016; Wang and Sueyoshi 2018; Dahlmann, Branicki, and Brammer 2019; Colmer and others 2022), with stronger effects for firms in energy-intensive sectors or in sectors with high abatement costs. Several advanced economies, among them *France*, *Japan*, *New Zealand*, and the *United States*, have regulations mandating firms' disclosures of climate risks (Carattini and others 2022).

Figure 1.17. Firms' Plans for Utilizing Incentives of Recent Climate Policy Packages in United States and Germany, Spring 2023
(Percent of firms surveyed)



Sources: Business Inflation Expectations Survey (Federal Reserve Bank of Atlanta); Bundesbank Online Panel—Firms; CFO Survey (Duke University, Federal Reserve Bank of Richmond, and Federal Reserve Bank of Atlanta); and IMF staff estimates.
Note: The stacked bars reflect the proportions of sampled firms that responded to surveys on their willingness to use incentives provided by the Inflation Reduction Act (firms in the *United States*) and Green Deal Industrial Plans (firms in *Germany*). The figure shows the share of firms that will use incentives in their country's policy packages. IRA = Inflation Reduction Act.

Figure 1.18. Firms' Responses to Financial Incentives to Invest in Emission Reduction, Spring 2023
(Percent of firms surveyed)



Sources: Business Inflation Expectations Survey (Federal Reserve Bank of Atlanta); Bundesbank Online Panel—Firms; CFO Survey (Duke University, Federal Reserve Bank of Richmond, and Federal Reserve Bank of Atlanta); and IMF staff estimates.
Note: The stacked bars reflect the proportions of sampled firms that responded to surveys on whether they will adjust investment in emission reductions based on incentives of the Inflation Reduction Act (firms in the *United States*) and Green Deal industrial policies (firms in *Germany*). The vertical bars show the share of firms that report cost as one of the top three constraints on investment in emission reduction. NA = not applicable or no change.

been, on average, remarkably resilient to the 2022 energy price shock, with no large cuts in firms' output, employment, or profitability (Box 1.3).[20] Firms have been able to pass the shocks to downstream firms or final consumers. Firms in *Germany*, which faced a larger spike in energy prices, responded to the price hike by both increasing or planning to increase investment in energy efficiency and reducing energy consumption.

Policymakers can also provide firms with fiscal incentives to enhance their green investment, although the effectiveness of these incentives depends on their design and implementation. Results from the same surveys show that some firms in *Germany* and the *United States* responded to the fiscal incentives announced in recent policy packages, such as the US Inflation Reduction Act of 2022 and the EU Green Deal Industrial Plan. Firms taking advantage of these fiscal incentives were often already investing in emission reductions, especially if they considered cost a major hurdle for investment (Figures 1.17 and 1.18).

[20]The surveys were conducted in collaboration with the Federal Reserve Bank of Atlanta's Business Inflation Expectations Survey; Duke University, Federal Reserve Bank of Richmond, and Federal Reserve Bank of Atlanta CFO Survey; and Bundesbank Online Panel in *Germany*.

However, the majority of firms in *Germany* reported that they were uncertain about the impact of policies on their climate-related investment plans.

This firm-level empirical analysis provides evidence that firms respond to regulations and fiscal incentives, which can accelerate the green transition, in particular when firms can calculate the impact of fiscal policies on their profitability from investing in the green transition. These findings offer several lessons for policy design and implementation:

- *Regulatory measures can facilitate the green transition, with varying effects.* Evidence suggests that firms adapt to stricter climate regulations by increasing investment. Policies that require firms to monitor their climate targets could reinforce higher carbon prices and are often associated with higher investment in low-carbon technologies by firms, particularly those in energy-intensive sectors.
- *Firms have been resilient on average and adapted to higher carbon prices.* Firms were broadly resilient to the 2022 energy price spikes and likely could adapt to higher energy prices by reducing energy consumption, investing in energy efficiency, and passing higher costs on to consumers or downstream

firms. Concerns that firms have difficulty adjusting to higher energy prices appear less relevant at the aggregate level, which strengthens the case for carbon pricing policies. Nonetheless, more adverse impacts to certain sectors or localities could occur if shocks are stronger and more persistent, suggesting the need for using a mix of instruments to accelerate the green transition.

- *Both policy design and implementation matter.* Fiscal incentives, in addition to higher carbon pricing, can encourage firms to invest. Policies need to be well communicated, including their horizon, their coverage, and the eligibility criteria for incentives, to provide certainty to firms in regard to the intended policies; otherwise, policy uncertainty could hamper investment (Berestycki and others 2022). Targeting can help minimize fiscal costs because some energy-intensive firms would have engaged in the same level of investment in green technologies even without fiscal incentives.

Conclusion

Climate action is an urgent global imperative, presenting policymakers with a fundamental trilemma between achieving climate goals, fiscal sustainability, and political feasibility. Prolonging the business-as-usual path and taking only moderate action will not contain global warming, leaving the world vulnerable to potential catastrophic consequences. The time to act is now, with a strong, clear, and concerted mix of policy efforts on the part of governments. Relying mostly on spending-based policies to achieve the net-zero-emissions goal will lead to fast-rising debt beyond the currently projected rising path, exacerbating risks to fiscal sustainability. Relying solely on carbon pricing to reach net zero, on the other hand, is likely to be politically unpalatable.

This chapter offers new insights to navigate this trilemma, recognizing that policymakers will need to strike a balance when crafting an optimal policy package. Achieving these joint goals will require a carefully calibrated mix of revenue- and spending-based mitigation instruments that involves carbon pricing—necessary but not sufficient to reach the net-zero-emission goals—and other complementary measures, such as transfers, green subsidies and investment, and regulatory measures. The optimal mix varies across countries. Evidence presented on firms' investment responses and resilience to recent energy price shocks also strengthens the case for using a mix of policies to facilitate decarbonization.

Climate policies to decarbonize economies will likely entail a net fiscal cost, which varies considerably across countries depending on size of investment needs, revenues from carbon pricing, and borrowing costs. Advanced economies with sufficient fiscal space could likely accommodate a small increase in debt if needed. Yet many emerging market and developing economies with high debt will find it more challenging to accommodate rising debt, especially as many face pressing priorities for climate adaptation and other development goals. This calls for action to enhance domestic revenue mobilization and improve spending efficiency, combined with efforts to catalyze private financing and undertake structural reforms to accelerate growth.

Addressing climate change involves a collective responsibility to ensure a sustainable, thriving, and resilient world. No single country can tackle it alone. Policymakers must coordinate their efforts by setting minimum carbon prices, removing trade barriers, avoiding costly subsidy races, and developing an international architecture to crowd-in private financing. Facilitating access to established low-carbon technologies and developing strong institutions in emerging market and developing economies can accelerate adoption and narrow technology gaps. Financial support for low-income countries will be crucial to meet their sizable development needs and enable them to cope with climate change. The IMF's Resilience and Sustainability Trust provides long-term financing that can help emerging market and developing economies achieve these goals.

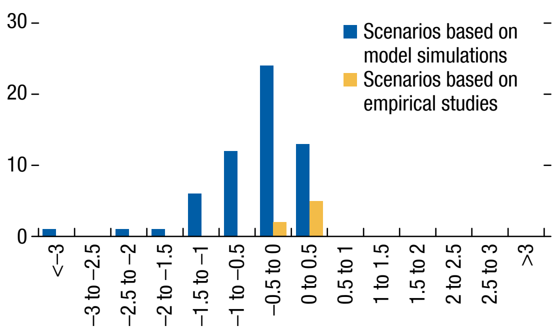
Box 1.1. GDP Impact of Climate Mitigation Policies

The impact of climate mitigation policies on the overall economy is important for policymakers. Analysis on the effects of climate mitigation policies on GDP and other macroeconomic variables has a long history. Can such policies raise GDP while also reducing emissions (a so-called double dividend) (Bovenberg 1999)? For instance, it has been argued that while carbon pricing increases the cost of energy, which could dampen output in the near term, using carbon revenues to reduce other distortionary taxes on labor or capital could raise output. Such a positive effect could be more likely in countries with large informal sectors, high levels of local air pollution, or low energy efficiency (Heine and Black 2019).

Studies have historically centered on model simulations, from which no consensus has emerged (Patuelli, Nijkamp, and Pels 2005; Freire-González 2018; Köppl and Schratzenstaller 2022). More recently, as an increasing number of countries have implemented climate mitigation policies, empirical evidence has been able to test the effect of carbon pricing on GDP. Figure 1.1.1 shows the estimated impacts on GDP of climate mitigation policies based on a new meta-analysis of both ex ante (simulation-based results prior to policy implementation) and ex post (empirical post-implementation) studies. Estimates vary across these studies owing to differences in revenue-recycling strategies, reform strength (such as tax rates and emission reductions achieved), country and sectoral coverage, and whether they consider broader endogenous behavioral responses on the part of households and firms. The simulation-based studies show large variation in effects on GDP, which are somewhat skewed toward negative (although small) impacts. By contrast, the small but growing number of empirical studies show a different pattern of mostly positive impacts (Yamazaki 2017; Bernard and Kichian 2021; Metcalf and Stock 2023).

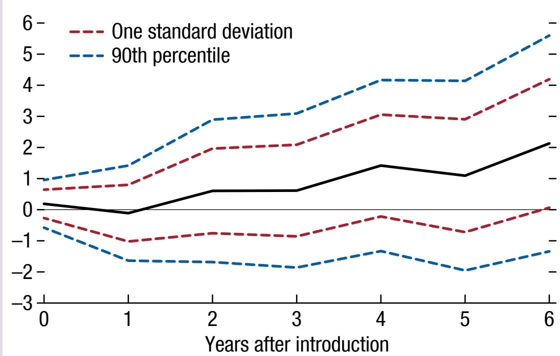
Figure 1.1.2 provides further support for this idea, showing the estimated cumulative impact on GDP from a $40 carbon price covering 30 percent of national emissions in EU countries during 1990–2019 (see also Metcalf and Stock 2023). The estimates implicitly capture the impact from revenue recycling (Online Annex 1.10). While the confidence intervals are wide, the point estimates suggest that the impact on GDP could be positive during the six years following the reform.

Figure 1.1.1. Meta-analysis: GDP Impact after Five Years
(Number of scenarios)



Source: IMF staff compilations.
Note: "Scenarios based on model simulations" includes all studies based on such simulations, especially those employing competitive general equilibrium models. The figure excludes scenarios that do not include recycling of revenues. Endpoints on horizontal axis are included on the left side of each range.

Figure 1.1.2. Impact of Carbon Prices at $40 a Ton on Real GDP for EU Countries, 1990–2019
(Percentage points)



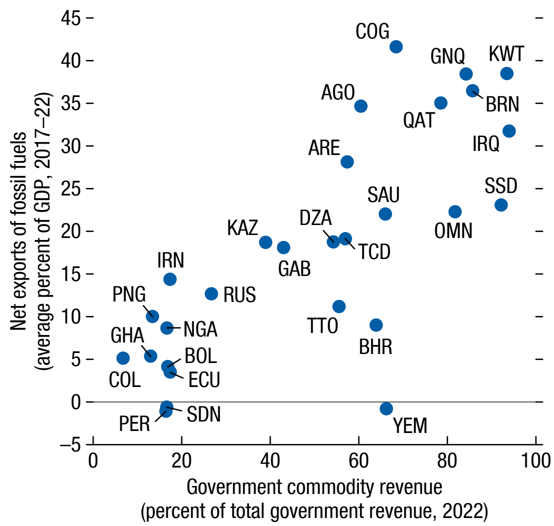
Source: IMF staff estimates based on Metcalf and Stock 2023.
Note: The carbon tax covers 30 percent of emissions.

Box 1.2. The Energy Transition of Fossil Fuel-Exporting Countries

Fossil fuel-exporting countries face additional challenges during the global energy transition. First, the scope they will have for using extractive revenues to finance economic development will be highly sensitive to the pace of global decarbonization efforts. Second, fossil fuel-exporting countries will need to continue to supply adequate volumes of hydrocarbon products as the world tries to lower demand for fossil fuels while safeguarding energy security. Third, they will need to reduce domestic greenhouse gas emissions, including those in extractive industries, to meet their climate targets consistent with the 2015 Paris Agreement (Mesa Puyo and others 2023).

In more than half of fossil fuel-exporting countries, receipts from commodities make up more than half of total fiscal revenues. At the same time, a quarter of these countries have fossil fuel exports greater than 25 percent of GDP (Figure 1.2.1). The fossil fuel-dependent countries are highly concentrated in Africa, the Middle East and Central Asia, and the Western Hemisphere. While some of the largest hydrocarbon producers, such as *Canada*, *China*, and the *United States*, have more diversified economies and revenue bases, reduced demand for fossil fuels will still affect subnational regions in these countries unevenly, given the way fossil fuel resources are concentrated.

Figure 1.2.1. High Dependence on Commodity Revenues and Exports for Fossil Fuel-Exporting Countries



Sources: IMF, World Economic Outlook database; UN Conference on Trade and Development; and IMF staff calculations.
Note: Commodity revenue includes all exploitable resources and fossil fuel revenue predominant among surveyed countries. Exports include other related primary products but exclude petrochemicals. Data labels in the figure use International Organization for Standardization (ISO) country codes.

The scope for using revenues from fossil fuel extraction to finance development or economic diversification will be highly sensitive to the global energy transition path (Figure 1.2.2). The model framework in Baunsgaard and Vernon (2023) provides a first approximation of the impact on fossil fuel revenue under various scenarios for the global energy transition outlined in International Energy Agency (2022b): a *stated-policies scenario*, an *announced-pledges scenario*, and a *net zero scenario*.[1] Analyses show that a number of countries are highly exposed to energy transition risks—for example, 10 countries currently earn more than half of their revenues from fossil fuels and could face at least an 80 percent drop in such revenues by 2040 under the net zero scenario (for example, *Equatorial Guinea*, *Iraq*, and *Oman*)—and nearly all countries face large declines in revenue by 2030 under the net zero scenario as a result of falling prices of, and demand for, fossil fuels. A slower global energy transition could permit certain fossil fuel producers to increase their market shares on account of relatively lower extraction costs or other comparative advantages (for example, *Iran*, *Kuwait*, and *Qatar*). While revenue declines in most regions under the announced-pledges scenario, revenues among members of the Organization of the Petroleum Exporting Countries are more resilient, as their collective market share rises over the medium term owing to lower extraction costs, although some face a decline in fossil fuel revenues by 2040. Fiscal policy

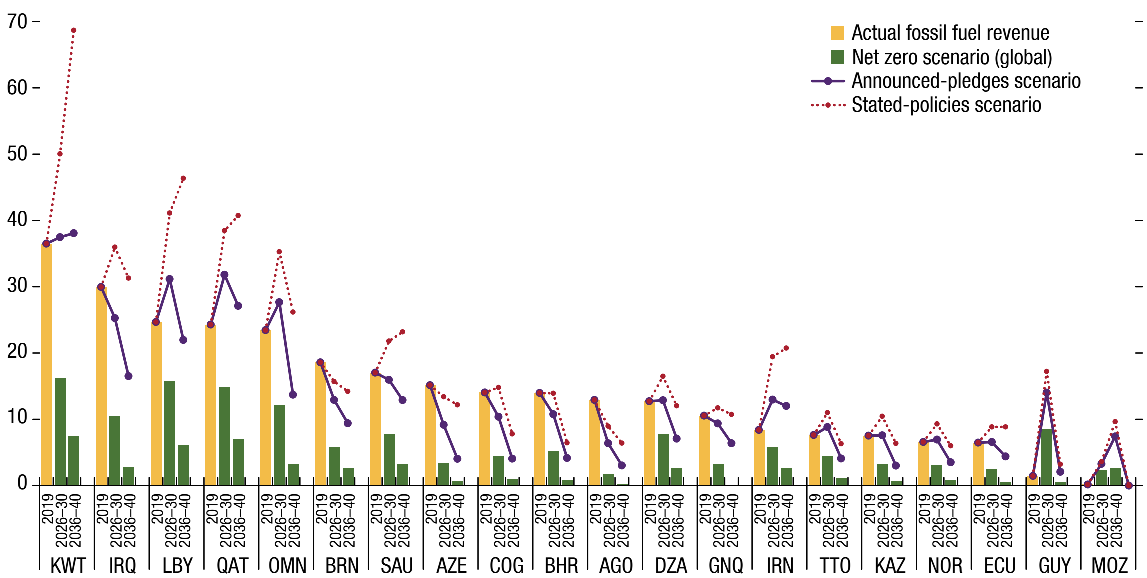
[1]In the stated-policies scenario, only current policies and those under development are implemented; oil prices are projected to rise, and demand peaks in 2035. In the announced-pledges scenario, governments achieve their mitigation targets; oil prices are projected to be stable, and demand peaks in 2024. In the net zero scenario, global warming is limited to 1.5 degrees Celsius, and there is no new development in the area of fossil fuels. As a simplifying assumption, GDP is held constant across scenarios. Results are sensitive to the assumptions regarding future prices of and demand for fossil fuels, as well as country-level production (see Baunsgaard and Vernon 2023).

Box 1.2 *(continued)*

can help address fiscal and economic challenges fossil fuel producers face during the energy transition:

- Fossil fuel producers should withdraw explicit fossil fuel subsidies—which are currently estimated at 5.1 percent of GDP, on average—and gradually phase in emission pricing policies (Black and others 2023a). Methane fees can efficiently reduce emissions in the extractive sector (Parry and others 2022). Carbon pricing provides incentives to switch to lower carbon sources of energy, freeing up hydrocarbons for export markets, which can improve health and generate fiscal revenue.
- Upstream fiscal regimes can be adjusted to shift risks associated with energy transition from investors to government if countries want to attract private investment to extend the life of fossil fuel reserves. Fiscal regimes reliant on profit-based instruments are progressive, as they allocate more risks and upside to the government at the cost of forgoing earlier and more stable revenues from production-based fiscal instruments (royalties). Given existing fiscal regime conditions and revenue objectives, governments should assess the appropriate mix of production and profit-based instruments to strike a balance between capturing a fair share of rents and securing a reasonable minimum share of revenue from extractive projects.
- National oil companies are key to advancing national policies for the energy transition. As those companies diversify into other businesses, it is important that they manage their balance sheets and associated fiscal risks carefully and that commercial basis drives their investment decisions.
- Fossil fuel producers need to build larger fiscal buffers and strengthen their fiscal frameworks to better manage resource wealth, as they face greater uncertainty during the energy transition. Increased savings of fossil fuel revenue in the near term could be managed under sovereign wealth funds (savings or stabilization funds) to ensure a just transition, promote intergenerational equity, and reduce procyclicality of fiscal policy (IMF 2012; Basdevant, Hooley, and Imamoglu 2021).

Figure 1.2.2. Fiscal Revenues for Select Fossil Fuel Producers under Various Energy Transition Scenarios
(Percent of GDP)



Source: IMF staff calculations.
Note: The figure shows selected fossil fuel-producing countries where fossil fuel revenues make the highest contribution to total revenue as well as large new producers such as *Guyana* and *Mozambique*. The outlook in regard to energy markets is based on International Energy Agency (2022b), which considers scenarios involving "stated policies," "announced pledges," and net zero emissions. The green bar for the net-zero-policy scenario shows the revenue decline for most countries relative to actual fossil fuel revenues in 2019. The purple and red lines show the revenues generated in the announced-pledges and the stated-policies scenarios. Data labels in the figure use International Organization for Standardization (ISO) country codes.

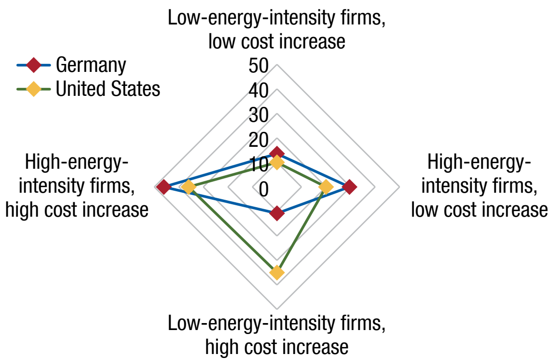
Box 1.3. How Have Firms Responded to Recent Energy Price Shocks?

The speed of the energy transition necessary to achieve the Paris Agreement climate goals has raised concerns that firms could face difficulties in adjusting to higher energy prices. The energy price spikes in 2022, partly driven by *Russia*'s invasion of *Ukraine*, provide a natural experiment for assessing whether firms are resilient when energy prices surge and how they adjust to such surges.

Two surveys, one among firms in *Germany* and the other among firms in the *United States*, show that more than three-quarters of firms in each country experienced a rise in their energy costs in 2022, with a higher share of firms in energy-intensive industries reporting an energy price shock (Figure 1.3.1). The increase was much larger in *Germany*, where nearly 20 percent of surveyed firms (four times higher than the share of firms in the *United States*) reported their energy costs as rising by more than 50 percent during 2022. In response, more than 40 percent of the firms surveyed in *Germany* passed on a quarter or more of the cost increase to downstream firms or customers, compared with 36 percent of surveyed firms in the *United States* (Online Annex 1.9).

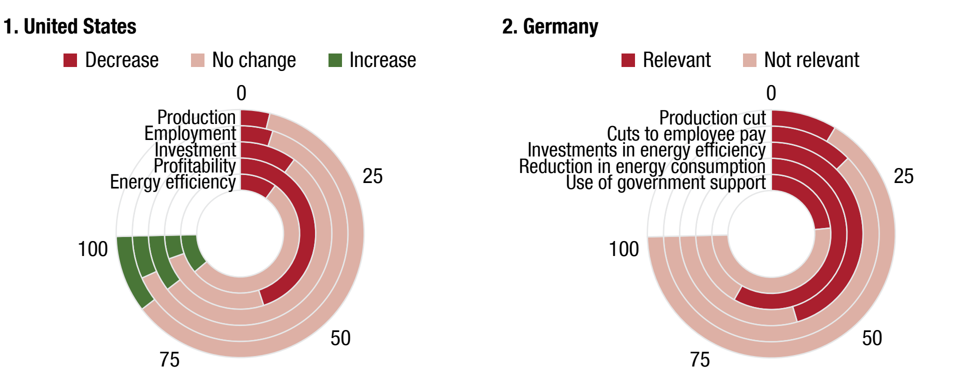
Less than 10 percent of surveyed firms in the *United States*, where the energy price shock was less acute, reported a cut in production or employment, but an even larger share reported an increase in either or both. The share of surveyed firms reporting a reduction in investment was somewhat higher, but so was the share of firms reporting an increase, with the majority reporting no change (Figure 1.3.2). Although 60 percent of the US firms surveyed reported a reduction in profitability, only 6 percent indicated that profitability had declined significantly. Overall, balance sheets of US firms surveyed seemed to have remained

Figure 1.3.1. Firms Experiencing Energy Price Shocks, 2022
(Percent of surveyed firms)



Sources: Business Inflation Expectations Survey (Federal Reserve Bank of Atlanta); Bundesbank Online Panel; CFO Survey (Duke University, Federal Reserve Bank of Atlanta, Federal Reserve Bank of Richmond); and IMF staff estimates.
Note: A large (small) increase in energy costs is defined as an increase of greater (less) than 50 percent in 2022. Firms are classified as high (low) energy intensity if their energy costs are greater (less) than 3 percent of their operational costs.

Figure 1.3.2. Impact of Rise in Energy Cost on Firms' Performance and Investment
(Percent of surveyed firms)



Sources: Business Inflation Expectations Survey (Federal Reserve Bank of Atlanta); Bundesbank Online Panel; CFO Survey (Duke University, Federal Reserve Bank of Atlanta, and Federal Reserve Bank of Richmond); and IMF staff estimates.
Note: The figure shows the proportion of firms experiencing a rise in energy costs that indicated a change in output, employment, investment, profitability, energy consumption, energy efficiency, or the use of government support measures (See Online Annex 1.9).

Box 1.3 *(continued)*

resilient to the energy price shock. Most firms that responded to the survey did not respond to higher energy prices by improving their energy efficiency.

This is in sharp contrast to what surveyed firms in *Germany* reported. In the face of a larger energy price shock (almost a doubling of nonresidential electricity prices relative to 2021 levels), 60 percent of surveyed firms in *Germany* reported investing or planning to invest in energy efficiency; and more than three-quarters reducing or planning to reduce their energy consumption. Somewhat surprisingly, only 12 percent of the responding firms reported an output loss. Hence, most surveyed firms in *Germany* were resilient by improving energy efficiency and reducing energy consumption. Differences between *Germany* and the *United States* may be attributable to the size and the perceived persistence of the shock or the level of government support received. For example, firms in *Germany* may have considered the energy price shock to be longer lasting and hence warranting investment in energy efficiency. Potential disruptions to firms could be larger if the shocks were more persistent.

References

Aghion, Philippe, and Peter Howitt. 2005. "Growth with Quality-Improving Innovations: An Integrated Framework." In *Handbook of Economic Growth*, Volume 1, part A, edited by Philippe Aghion and Steven N. Durlauf. Amsterdam: Elsevier.

Akanbi, Olusegun, William Gbohoui, and W. Raphael Lam. 2023. "Calibrating Fiscal Rules: A Consideration of Natural Disaster Risks." IMF Technical Notes and Manuals 2023/02, International Monetary Fund, Washington, DC.

Aligishiev, Zamid, Matthieu Bellon, and Emanuele Massetti. 2022. "Macro-Fiscal Implications of Adaptation to Climate Change." IMF Staff Climate Note 2022/002, International Monetary Fund, Washington, DC.

Bartolini, David, Valerie Cerra, Yujin Kim, and Johanna Tiedemann. 2023. "A Macroeconomic Model for Climate and Sustainable Development: The C-SDG Model." Unpublished, International Monetary Fund, Washington, DC.

Basdevant, Olivier, John Hooley, and Eslem Imamoglu. 2021. "How to Design a Fiscal Strategy in a Resource-Rich Country." How-To Note 21/01, International Monetary Fund, Washington, DC.

Battersby, Bryn, Raphael Espinoza, Jason Harris, GeeHee Hong, Sandra Lizarazo, Paolo Mauro, and Amanda Sayegh. 2022. "The State as Financier of Last Resort", IMF Staff Discussion Note 2022/003, International Monetary Fund, Washington, DC.

Baunsgaard, Thomas, and Nate Vernon. 2023. "Climate Change Mitigation and Extractive Industries: Scenario Analysis of Revenue Implications." Unpublished, International Monetary Fund, Washington, DC.

Benitez, Juan Carlos, Mario Mansour, Miguel Pecho, and Charles Vellutini. 2023. "Building Tax Capacity in Developing Countries." IMF Staff Discussion Note 2023/006, International Monetary Fund, Washington, DC.

Berestycki, Clara, Stefano Carattini, Antione Dechezleprêtre, and Tobias Kruse. 2022. "Measuring and Assessing the Effects of Climate Policy Uncertainty." OECD Economics Department Working Paper 1724, Organisation for Economic Co-operation and Development, Paris.

Bernard, Jean-Thomas, and Maral Kichian. 2021. "The Impact of a Revenue-Neutral Carbon Tax on GDP Dynamics: The Case of British Columbia." *The Energy Journal* 42 (3): 205–24.

Bistline, John, Neil Mehrotra, and Catherine Wolfram. 2023. "Economic Implications of the Climate Provisions for the Inflation Reduction Act." NBER Working Paper 31267, National Bureau of Economic Research, Cambridge, MA.

Black, Simon, Jean Chateau, Florence Jaumotte, Ian Parry, Gregor Schwerhoff, Sneha Thube, and Karlygash Zhunussova. 2022a. "Getting on Track to Net Zero: Accelerating a Global Just Transition in This Decade." IMF Staff Climate Note 2022/010, International Monetary Fund, Washington, DC.

Black, Simon, Danielle Minnett, Ian Parry, James Roaf, and Karlygash Zhunussova. 2022b. "A Framework for Comparing Climate Mitigation Policies across Countries." IMF Working Paper 22/254, International Monetary Fund, Washington, DC.

Black, Simon, Antung A. Liu, Ian Parry, and Nate Vernon. 2023a. "IMF Fossil Fuel Subsidies Data: 2023 Update." IMF Working Paper 23/169, International Monetary Fund, Washington, DC

Black, Simon, Ian Parry, Victor Mylonas, Nate Vernon, and Karlygash Zhunussova. 2023b. "The IMF-World Bank Climate Policy Assessment Tool (CPAT): A Model to Help Countries Mitigate Climate Change." IMF Working Paper 23/128, International Monetary Fund, Washington, DC.

Black, Simon, Ian Parry, and Karlygash Zhunussova. 2023. "Getting on Track to Net Zero: An IMF Staff Update for the COP28 Global Stock Take." Unpublished, International Monetary Fund, Washington, DC.

Bovenberg, A. Lans. 1999. "Green Tax Reforms and the Double Dividend: An Updated Reader's Guide." *International Tax and Public Finance* 6 (3): 421–43.

Brutscher, Philipp-Bastian, Andrea Coali, Julie Delanote, and Peter Harasztosi. 2020. "EIB Group Survey on Investment and Investment Finance: A Technical Note on Data Quality." EIB Working Paper 2020/08, European Investment Bank, Luxembourg.

Budina, Nina, Christian Ebeke, Florence Jaumotte, Andrea Medici, Augustus Panton, Marina Tavares, and Bella Yao. 2023. "Structural Reforms to Accelerate Green Growth and Ease Policy Trade-Offs in EMDEs." Unpublished, International Monetary Fund, Washington, DC.

Capelle, Damien, Nicola Pierri, and German Villegas Bauer. 2023. "Mitigating Climate Change at the Firm Level: Mind the Laggards." Unpublished, International Monetary Fund, Washington, DC.

Carattini, Stefano, Edgar Hertwich, Givi Melkadze, and Jeffrey G. Shrader. 2022. "Mandatory Disclosure Is Key to Address Climate Risks: Financial Regulations Would Help Signal Risks to Investors." *Science* 378 (6618): 352–54.

Chang, Yongsung, João Gomes, and Frank Schorfheide. 2002. "Learning-by-doing as a Propagation Mechanism." *American Economic Review* 92 (5): 1498–520.

Cherif, Reda, Fuad Hasanov, Nikola Spatafora, Rahul Giri, Dimitre Milkov, Saad Quayyum, Gonzalo Salinas, and others. 2022. "Industrial Policy for Growth and Diversification: A Conceptual Framework." IMF Departmental Paper 2022/017, International Monetary Fund, Washington, DC.

Coady, David, Ian W. H. Parry, and Baoping Shang. 2018. "Energy Price Reform: Lessons for Policymakers." *Review of Environmental Economics and Policy* 12 (2): 197–219.

Colmer, Jonathan, Ralf Martin, Mirabelle Muûls, and Ulrich J. Wagner. 2022. "Does Pricing Carbon Mitigate Climate Change? Firm-Level Evidence from the European Union Emissions Trading Scheme." CEPR Discussion Paper DP16982, Centre for Economic Policy Research, London.

Dabla-Norris, Era, Thomas Helbling, Kenichiro Kashiwase, Giacomo Magistretti, and Mouhamadou Sy. 2023a. "Asia's Perspectives on Climate Change: Policies, Perceptions, and Gaps." Unpublished, International Monetary Fund, Washington, DC.

Dabla-Norris, Era, Thomas Helbling, Salma Khalid, Hibah Khan, Giacomo Magistretti, Alexandre Sollaci, and Krishna Srinivasan. 2023b. "Public Perceptions of Climate Mitigation Policies: Evidence from Cross-Country Surveys." IMF Staff Discussion Note 2023/002, International Monetary Fund, Washington, DC.

Dabla-Norris, Era, Salma Khalid, Giacomo Magistretti, and Aleandre Sollaci. Forthcoming. "Public Support for Climate Change Mitigation Policies: A Cross-Country Survey." IMF Working Paper, International Monetary Fund, Washington, DC.

Dahlmann, Frederik, Layla Branicki, and Stephen Brammer. 2019. "Managing Carbon Aspirations: The Influence of Corporate Climate Change Targets on Environmental Performance." *Journal of Business Ethics* 158 (1): 1–24.

de Mooij, Ruud, Simon Black, Vitor Gaspar, Ian Parry, and Karlygash Zhunussova. 2023. "How Does Decarbonization Change the Fiscal Equation?" Presentation at Peterson Institute of International Economics, Washington, DC, June 5.

Dechezleprêtre, Antoine, Daniel Nachtigall, and Frank Venmans. 2018. "The Joint Impact of the European Union Emissions Trading System on Carbon Emissions and Economic Performance." OECD Economics Department Working Paper 1515, Organisation for Economic Co-operation and Development, Paris.

Deutsche Bundesbank. 2023. "Germany as a Location of Business: Selected Aspects of Current Dependencies and Medium-Term Challenges." Monthly Report, September 2023, Frankfurt.

Dietz, Simon, and Nicolas Stern. 2015. "Endogenous Growth, Convexity of Damage and Climate Risk: How Nordhaus' Framework Supports Deep Cuts in Carbon Emissions." *The Economic Journal* 125 (583): 574–620.

Ditlevsen, Peter, and Susanne Ditlevsen. 2023. "Warning of a Forthcoming Collapse of the Atlantic Meridional Overturning Circulation." *Nature Communications* 14 (1): 4254.

Douenne, Thomas, and Adrien Fabre. 2002. "Yellow Vests, Pessimistic Beliefs, and Carbon Tax Aversion." *American Economic Journal: Economic Policy* 14 (1): 81–110.

European Investment Bank. 2022. "EIB Investment Survey 2022: European Union Overview." Luxembourg.

European Investment Bank. 2023. "EIB Investment Report 2022/2023: Resilience and Renewal in Europe." Luxembourg.

Freire-González, Jaume. 2018. "Environmental Taxation and the Double Dividend Hypothesis in CGE Modelling Literature: A Critical Review." *Journal of Policy Modeling* 40 (1): 194–223.

Georgieva, Kristalina. 2022. "Getting Back on Track to Net Zero: Three Critical Priorities for COP27." *IMF Blog*, November 4. https://www.imf.org/en/Blogs/Articles/2022/11/04/getting-back-on-track-to-net-zero-three-critical-priorities-for-cop27

Gourinchas, Pierre-Olivier, Gregor Schwerhoff, and Antonio Spilimbergo. 2023. "New Challenges to Climate Policies." Unpublished, International Monetary Fund, Washington, DC.

Harris, Jason, Tjeerd Tim, and Jyoti Rahman. 2023. "Macro-Fiscal Risks of Climate Change: User Guide for the Quantitative Climate Change Risk Assessment Fiscal Tool (Q-CRAFT)." Unpublished, International Monetary Fund, Washington, DC.

Harris, Jason, Tjeerd Tim, John Zohrab, Viera Karolova, and Jyoti Rahman. 2022. "Georgia: Technical Assistance Report—Updating the Balance Sheet and Quantifying Fiscal Risks from Climate Change." IMF Country Report 22/150, Washington, DC.

Heine, Dirk, and Simon Black. 2019. "Benefits beyond Climate: Environmental Tax Reform in Developing Countries." In *Fiscal Policies for Development and Climate Action*, edited by Miria A. Pigato. Washington, DC: World Bank.

Intergovernmental Panel on Climate Change (IPCC). 2021. "Technical Summary." In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Valérie Masson-Delmotte, Panmao Zhai, Anna Pirani, Sarah L. Connors, Clotilde Péan, Sophie Berger, Nada Caud, and others. Cambridge, UK: Cambridge University Press.

International Energy Agency (IEA). 2020. *Energy Technology Perspectives 2020*. Paris.

International Energy Agency (IEA). 2021. *Net Zero by 2050: A Roadmap for the Global Energy Sector*. Paris.

International Energy Agency (IEA). 2022a. *Technology and Innovation Pathways for Zero-Carbon-Ready Buildings by 2030: A Strategic Vision from the IEA Technology Collaboration Programmes*. Paris.

International Energy Agency (IEA). 2022b. *World Energy Outlook 2022*. Paris.

International Monetary Fund (IMF). 2012. "Macroeconomic Policy Frameworks for Resource-Rich Development Countries." IMF Policy Paper, Washington, DC.

International Monetary Fund (IMF). 2021. "Reaching Net Zero Emissions." G20 Background Note, Washington, DC.

International Monetary Fund (IMF). 2023a. "Kenya: Fifth Reviews Under the Extended Fund Facility and Extended Credit Facility Arrangements and Request for a 20-month

Arrangement under the Resilience and Sustainability Facility, Requests for Extension, Rephasing, and Augmentation of Access, Modification of a Performance Criterion, and Monetary Policy Consultation Clause—Press Release; Staff Report; and Statement by the Executive Director for Kenya." IMF Country Report 23/266, Washington, DC.

International Monetary Fund (IMF). 2023b. *Data for a Greener World: A Guide for Practitioners and Policymakers*, edited by Serkan Arslanalp, Kristina Kostial, and Gabriel Quiros-Romero, Washington, DC.

International Monetary Fund (IMF). Forthcoming. "How to Cover Industrial Policy Issues in Country Work." Washington, DC.

International Renewable Energy Agency (IRENA). 2022. *Renewable Power Generation Costs in 2021*. Abu Dhabi.

Ioannou, Ioannis, Shelley Xin Li, and George Serafeim. 2016. "The Effect of Target Difficulty on Target Completion: The Case of Reducing Carbon Emissions." *Accounting Review* 91 (5): 1467–92.

Kalantzis, Fotios, Salma Khalid, W. Raphael Lam, Alexandra Solovyeva, and Marcin Wolski. Forthcoming. "The Impact of Stringent Climate Policies on Firms Regulated under the EU Emissions Trading Scheme." IMF Working Paper, International Monetary Fund, Washington, DC.

Kammer, Alfred. 2023. "Europe, and the World, Should Use Green Subsidies Cooperatively." *IMF Blog*, May 11. https://www.imf.org/en/Blogs/Articles/2023/05/11/europe-and-the-world-should-use-green-subsidies-cooperatively

Känzig, Diego R. 2023. "The Unequal Economic Consequences of Carbon Pricing." NBER Working Paper 31221, National Bureau of Economic Research, Cambridge, MA.

Keen, Michael, Ian Parry, and James Roaf. 2021. "Border Carbon Adjustments: Rationale, Design, and Impact." IMF Working Paper 21/239, International Monetary Fund, Washington, DC.

Kiessling, Johan. 2007. "Institutions and ICT Technology Adoption." Unpublished, Department of Economics, Stockholm University, Stockholm.

Klenert, David, Linus Mattauch, Emmanuel Combet, Ottmar Edenhofer, Cameron Hepburn, Ryan Rafaty, and Nicholas Stern. 2018. "Making Carbon Pricing Work for Citizens." *Nature Climate Change* 8 (8): 669–77.

Köppl, Angela, and Margit Schratzenstaller. 2022. "Carbon Taxation: A Review of the Empirical Literature." *Journal of Economic Surveys* 37 (4): 1353–88.

Kotlikoff, Laurence J., Felix Kubler, Andrey Polbin, and Simon Scheidegger. 2021. "Can Today's and Tomorrow's World Uniformly Gain from Carbon Taxation?" NBER Working Paper 29224, National Bureau of Economic Research, Cambridge, MA.

Manca, Fabio. 2009. "Technology Catching-Up and the Role of Institutions." Research Institute of Applied Economics Working Paper 2009/12, University of Barcelona, Barcelona.

McKay, David, Jesse Abrams, Ricarda Winkelmann, Boris Sakschewski, Sina Loriani, Ingo Fetzer, Sarah Cornell, and others. 2022. "Exceeding 1.5°C Global Warming Could Trigger Multiple Climate Tipping Points." *Science* 377 (6611).

Mercure, Jean-Francois, Hector Pollitt, Jorge E. Viñuales, Neil Edwards, Phil Holden, Unnada Chewpreecha, Pablo Salas, and others. 2018. "Macroeconomic Impact of Stranded Fossil Fuel Assets." *Nature Climate Change* 8 (7): 588–93.

Mesa Puyo, Diego, Augustus Panton, Tarun Sridhar, Martin Stuermer, Christoph Ungerer, and Alice Tianbo Zhang. 2023. "Fossil Fuel Exporters and the Energy Transition." Unpublished, International Monetary Fund, Washington, DC.

Metcalf, Gilbert. 2023. "Five Myths about Carbon Pricing." NBER Working Paper 31104, National Bureau of Economic Research, Cambridge, MA.

Metcalf, Gilbert E., and James H. Stock. 2023. "The Macroeconomic Impact of Europe's Carbon Taxes." *American Economic Journal: Macroeconomics* 15 (3): 265–86.

Nordhaus, William. 2021. *The Spirt of Green: The Economics of Collisions and Contagions in a Crowded World*. Princeton, NJ: Princeton University Press.

Parry, Ian, Peter Dohlman, Cory Hillier, Martin Kaufman, Kyung Kwak, Florian Misch, James Roaf, and others. 2021. "Carbon Pricing: What Role for Border Carbon Adjustments?" IMF Staff Climate Note 2021/004, International Monetary Fund, Washington, DC.

Parry, Ian, Simon Black, Danielle Minnett, Victor Mylonas, and Nate Vernon. 2022. "How to Cut Methane Emissions." IMF Staff Climate Note 2022/008, International Monetary Fund, Washington, DC.

Parry, Ian, Simon Black, Danielle Minnett, and Karlygash Zhunussova. 2023. "Policies to Decarbonize Industry While Addressing Competitiveness and Carbon Leakage." Unpublished, International Monetary Fund, Washington, DC.

Parry, Ian, Simon Black, and Karlygash Zhunussova. 2022. "Carbon Taxes or Emissions Trading Systems?: Instrument Choice and Design." IMF Staff Climate Note 2022/006, International Monetary Fund, Washington, DC.

Patuelli, Roberto, Peter Nijkamp, and Eric Pels. 2005. "Environmental Tax Reform and the Double Dividend: A Meta-analytical Performance Assessment." *Ecological Economics* 55 (4): 564–83.

Pisani-Ferry, Jean, and Selma Mahfouz. 2023. "The Economic Implications of Climate Action." Unpublished.

Stern, Nicholas, and Anna Valero. 2021. "Innovation, Growth and the Transition to Net-Zero Emissions." *Research Policy* 50 (9): 104293.

Traum, Nora, and Shu-Chun S. Yang. 2015. "When Does Government Debt Crowd Out Investment?" *Journal of Applied Econometrics* 30 (1): 24–45.

United Kingdom Office of Budget Responsibility. 2021. "Climate Change" (Chapter 3). In *Fiscal Risks Report 2021*. London.

United Nations Conference on Trade and Development (UNCTAD). 2022a. "Tackling Debt and Climate Challenges in Tandem: A Policy Agenda." UNCTAD Policy Brief 104, Geneva.

United Nations Conference on Trade and Development (UNCTAD). 2022b. *Technology and Innovation Report 2023: Opening Green Windows; Technological Opportunities for a Low-Carbon World.* Geneva.

Wang, Derek D., and Toshiyuki Sueyoshi. 2018. "Climate Change Mitigation Targets Set by Global Firms: Overview and Implications for Renewable Energy." *Renewable and Sustainable Energy Reviews* 94 (October): 386–98.

Way, Rupert, Matthew C. Ives, Penny Mealy, and J. Doyne Farmer. 2022. "Empirically Grounded Technology Forecasts and the Energy Transition." *Joule* 6 (9): 2057–82.

Yamazaki, Akio. 2017. "Jobs and Climate Policy: Evidence from British Columbia's Revenue-Neutral Carbon Tax." *Journal of Environmental Economics and Management* 83: 197–216.

Ziegler, Micah S., and Jessika E. Trancik. 2021a. "Data Series for Lithium-Ion Battery Technologies." Harvard Dataverse, V1. https://doi.org/10.7910/DVN/9FEJ7C

Ziegler, Micah S., and Jessika E. Trancik. 2021b. "Re-examining Rates of Lithium-Ion Battery Technology Improvement and Cost Decline." *Energy & Environmental Science* 14 (4): 1635–51.

ECONOMY ABBREVIATIONS

Code	Name
AFG	Afghanistan
AGO	Angola
ALB	Albania
AND	Andorra
ARE	United Arab Emirates
ARG	Argentina
ARM	Armenia
ATG	Antigua and Barbuda
AUS	Australia
AUT	Austria
AZE	Azerbaijan
BDI	Burundi
BEL	Belgium
BEN	Benin
BFA	Burkina Faso
BGD	Bangladesh
BGR	Bulgaria
BHR	Bahrain
BHS	Bahamas, The
BIH	Bosnia and Herzegovina
BLR	Belarus
BLZ	Belize
BOL	Bolivia
BRA	Brazil
BRB	Barbados
BRN	Brunei Darussalam
BTN	Bhutan
BWA	Botswana
CAF	Central African Republic
CAN	Canada
CHE	Switzerland
CHL	Chile
CHN	China
CIV	Côte d'Ivoire
CMR	Cameroon
COD	Congo, Democratic Republic of the
COG	Congo, Republic of
COL	Colombia
COM	Comoros
CPV	Cabo Verde
CRI	Costa Rica
CYP	Cyprus
CZE	Czech Republic
DEU	Germany
DJI	Djibouti
DMA	Dominica

Code	Name
DNK	Denmark
DOM	Dominican Republic
DZA	Algeria
ECU	Ecuador
EGY	Egypt
ERI	Eritrea
ESP	Spain
EST	Estonia
ETH	Ethiopia
FIN	Finland
FJI	Fiji
FRA	France
FSM	Micronesia, Federated States of
GAB	Gabon
GBR	United Kingdom
GEO	Georgia
GHA	Ghana
GIN	Guinea
GMB	Gambia, The
GNB	Guinea-Bissau
GNQ	Equatorial Guinea
GRC	Greece
GRD	Grenada
GTM	Guatemala
GUY	Guyana
HKG	Hong Kong Special Administrative Region
HND	Honduras
HRV	Croatia
HTI	Haiti
HUN	Hungary
IDN	Indonesia
IND	India
IRL	Ireland
IRN	Iran
IRQ	Iraq
ISL	Iceland
ISR	Israel
ITA	Italy
JAM	Jamaica
JOR	Jordan
JPN	Japan
KAZ	Kazakhstan
KEN	Kenya
KGZ	Kyrgyz Republic
KHM	Cambodia
KIR	Kiribati

Code	Name
KNA	St. Kitts and Nevis
KOR	Korea
KWT	Kuwait
LAO	Lao P.D.R.
LBN	Lebanon
LBR	Liberia
LBY	Libya
LCA	St. Lucia
LKA	Sri Lanka
LSO	Lesotho
LTU	Lithuania
LUX	Luxembourg
LVA	Latvia
MAR	Morocco
MDA	Moldova
MDG	Madagascar
MDV	Maldives
MEX	Mexico
MHL	Marshall Islands
MKD	North Macedonia
MLI	Mali
MLT	Malta
MMR	Myanmar
MNE	Montenegro
MNG	Mongolia
MOZ	Mozambique
MRT	Mauritania
MUS	Mauritius
MWI	Malawi
MYS	Malaysia
NAM	Namibia
NER	Niger
NGA	Nigeria
NIC	Nicaragua
NLD	Netherlands, The
NOR	Norway
NPL	Nepal
NRU	Nauru
NZL	New Zealand
OMN	Oman
PAK	Pakistan
PAN	Panama
PER	Peru
PHL	Philippines
PLW	Palau
PNG	Papua New Guinea
POL	Poland
PRT	Portugal
PRY	Paraguay
QAT	Qatar

Code	Name
ROU	Romania
RUS	Russian Federation
RWA	Rwanda
SAU	Saudi Arabia
SDN	Sudan
SEN	Senegal
SGP	Singapore
SLB	Solomon Islands
SLE	Sierra Leone
SLV	El Salvador
SMR	San Marino
SOM	Somalia
SRB	Serbia
SSD	South Sudan
STP	São Tomé and Príncipe
SUR	Suriname
SVK	Slovak Republic
SVN	Slovenia
SWE	Sweden
SWZ	Eswatini
SYC	Seychelles
SYR	Syria
TCD	Chad
TGO	Togo
THA	Thailand
TJK	Tajikistan
TKM	Turkmenistan
TLS	Timor-Leste
TON	Tonga
TTO	Trinidad and Tobago
TUN	Tunisia
TUR	Türkiye
TUV	Tuvalu
TWN	Taiwan Province of China
TZA	Tanzania
UGA	Uganda
UKR	Ukraine
URY	Uruguay
USA	United States
UZB	Uzbekistan
VCT	St. Vincent and the Grenadines
VEN	Venezuela
VNM	Vietnam
VUT	Vanuatu
WSM	Samoa
YEM	Yemen
ZAF	South Africa
ZMB	Zambia
ZWE	Zimbabwe

GLOSSARY

Adaptation[1] The process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.

Ambition gap[1] A gap between emission pledges and emission reduction pathways consistent with 1.5–2°C.

Border carbon adjustment Levy charged on the unpriced carbon emissions embodied in imports (perhaps with remittances for domestic carbon taxes on exports).

Business as usual (BAU)[1] Scenarios that are based on the assumption that no mitigation policies or measures will be implemented beyond those that are already in force and/or are legislated or planned to be adopted. Equivalent to no policy scenario.

Carbon dioxide (CO_2) The main greenhouse gas, produced from burning fossil fuels, manufacturing cement, and forest practices. CO_2 has an average atmospheric residence time of 100 years.

Carbon dioxide capture and storage[1] A process in which a relatively pure stream of carbon dioxide (CO2) from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for long-term isolation from the atmosphere.

Carbon leakage Changes in sectoral emissions arising from moving production to countries with laxer emission standards.

Carbon price[1] The price for avoided or released carbon dioxide (CO2) or CO2-equivalent emissions. This may refer to the rate of a carbon tax, or the price of emission permits.

Carbon tax A tax imposed on CO_2 releases emitted largely through the combustion of carbon-based fossil fuels. Administratively, the easiest way to implement the tax is through taxing the supply of fossil fuels—coal, oil, and natural gas—in proportion to their carbon content.

[1] Definition obtained from the Intergovernmental Panel on Climate Change (https://apps.ipcc.ch/glossary/).

Climate target[1] Climate target refers to a temperature limit, concentration level, or emissions reduction goals by a certain amount over a given time horizon.

Contingent liabilities Obligations that are not explicitly recorded on government balance sheets and that arise only in the event of a particular discrete situation, such as a crisis.

Cyclically adjusted balance (CAB) Difference between the overall balance and the automatic stabilizers; equivalently, an estimate of the fiscal balance that would apply under current policies if output were equal to potential.

Cyclically adjusted primary balance (CAPB) Cyclically adjusted balance excluding net interest payments (interest expenditure minus interest revenue).

Decarbonization The process by which countries, individuals, or other entities aim to achieve zero fossil carbon existence. Typically refers to a reduction of the carbon emissions associated with electricity, industry, and transport.

Emissions-trading system A market-based policy to reduce emissions (sometimes referred to as cap-and-trade). Covered sources are required to hold allowances for each ton of their emissions or (in an upstream program) the embodied emissions content in fuels. The total quantity of allowances is fixed, and market trading of allowances establishes a market price for emissions. Auctioning the allowances provides a valuable source of government revenue.

Externality A cost imposed by the actions of individuals or firms on other individuals or firms (possibly in the future, as in the case of climate change) that the former does not consider.

Feebate This policy would impose a sliding scale of fees on firms with emission rates (for example,

CO_2 per kilowatt-hour) above a "pivot point" level and corresponding subsidies for firms with emission rates below the pivot point. Alternatively, the feebate might be applied to energy consumption rates (for example, gasoline per mile driven) rather than emission rates. Feebates can exploit many (but not all) of the mitigation opportunities promoted by carbon taxes but without a large increase in energy prices.

Fiscal buffer Fiscal space created by saving budgetary resources and reducing public debt in good times.

Fiscal consolidation Fiscal policy that reduces government deficits and government debt.

Fiscal framework The set of rules, procedures, and institutions that guide fiscal policy.

Fiscal space The room for undertaking discretionary fiscal policy (increasing spending or reducing taxes) relative to existing plans without endangering market access and debt sustainability.

General government All government units and all nonmarket, nonprofit institutions that are controlled and mainly financed by government units comprising the central, state, and local governments; includes social security funds and does not include public corporations or quasi corporations.

Government financing needs (also *Gross financing needs*) Overall new borrowing requirement plus debt maturing during the year.

Government credit guarantees Governments can undertake payment of a debt or liabilities in the event of a default by the primary creditor. The most common type is a government-guaranteed loan, which requires government to repay any amount outstanding on a loan in the event of default. In some contracts, governments provide a revenue or demand guarantee. The budget costs related to guarantees are usually not recognized in the budget without any upfront cost, but they create a contingent liability, with the government exposed to future calls on guarantees and fiscal risks.

Greenhouse gas A gas in the atmosphere that is transparent to incoming solar radiation but traps and absorbs heat radiated from the earth. CO_2 is easily the most predominant greenhouse gas.

Green industrial policies Policies to promote low-carbon technologies through targeted measures, such as subsidies and tax incentives on specific domestic firms, industries, sectors, or regions.

Green subsidies/investment Subsidies/investment to support environmentally friendly technologies, practices, and behaviors.

Green transition Transition to net zero emissions. See ***Net zero emissions***

Gross debt All liabilities that require future payment of interest and/or principal by the debtor to the creditor. This includes debt liabilities in the form of special drawing rights, currency, and deposits; debt securities; loans; insurance, pension, and standardized guarantee programs; and other accounts payable. (See the IMF's 2001 *Government Finance Statistics Manual* and *Public Sector Debt Statistics Manual*.) The term "public debt" is used in the *Fiscal Monitor*, for simplicity, as synonymous with gross debt of the general government, unless specified otherwise. (Strictly speaking, public debt refers to the debt of the public sector as a whole, which includes financial and nonfinancial public enterprises and the central bank.)

Gross financing needs See ***Government financing needs***

Headline fiscal balance See ***Overall fiscal balance***

Just transition Measures to provide support for households and firms to ensure a fair distribution of costs and benefits as a part of comprehensive mitigation strategy.

Mitigation[1] A human intervention to reduce emissions or enhance the sinks of greenhouse gases, including carbon dioxide removal options.

Nationally Determined Contribution (NDC) Climate strategies, including mitigation commitments, submitted by 190 parties for the Paris Agreement. Countries are required to report progress on implementing NDCs every two years and, since 2020, to submit revised NDCs (which are expected to contain progressively more stringent mitigation pledges) every five years.

Net debt Gross debt minus financial assets corresponding to debt instruments. These financial assets are monetary gold and special drawing rights;

[1] Definition obtained from the Intergovernmental Panel on Climate Change (https://apps.ipcc.ch/glossary/).

currency and deposits; debt securities; loans, insurance, pensions, and standardized guarantee programs; and other accounts receivable. In some countries, the reported net debt can deviate from this definition based on available information and national fiscal accounting practices.

Net (financial) worth Net worth is a measure of fiscal solvency. It is calculated as assets minus liabilities. Net financial worth is calculated as financial assets minus liabilities.

Network externality Occurs when additional infrastructure needed for one investor (for example, to connect a remote renewables site to the power grid) could potentially benefit other firms.

Net zero emissions[1] Balance at a global scale of residual carbon dioxide emissions with the same amount of carbon dioxide removal.

Nonfinancial public sector General government plus nonfinancial public corporations.

Overall fiscal balance (also *Headline fiscal balance*) Net lending and borrowing, defined as the difference between revenue and total expenditure, using the IMF's 2001 *Government Finance Statistics Manual* (GFSM 2001). Does not include policy lending. For some countries, the overall balance is still based on the GFSM 1986, which defines it as total revenue and grants minus total expenditure and net lending.

Paris Agreement An international accord (ratified in 2016) on climate mitigation, adaptation, and finance. The Agreement's central objective is to contain global average temperature increases to 1.5–2°C above preindustrial levels.

Price subsidies Price subsidies are measure that keep prices for end users below market levels, or for suppliers above market levels. Subsidies can take various forms including direct transfers, but also indirect support such as tax exemptions, price controls, or rebates.

Primary balance Overall balance excluding net interest payments (interest expenditure minus interest revenue).

Progressive (or regressive) taxes Taxes that feature an average tax rate that rises (or falls) with income.

[1] Definition obtained from the Intergovernmental Panel on Climate Change (https://apps.ipcc.ch/glossary/).

Public debt See ***Gross debt***

Public sector Includes all resident institutional units that are deemed to be controlled by the government. It includes general government and resident public corporations.

Research and development Innovative activities undertaken by corporations or governments in developing new products or technologies.

Revenue recycling Use of (carbon) tax revenues to, for example, lower other taxes on households and firms or fund public investments.

Shadow carbon price The social cost of emitting a marginal ton of carbon or the social benefit of abating a ton of carbon.

Social protection The social protection system consists of policies designed to reduce individuals' exposures to risks and vulnerabilities and to enhance their capacity to manage negative shocks such as unemployment, sickness, poverty, disability, and old age. It has three broad categories: (1) social safety net programs (noncontributory transfer programs to ensure a minimum level of economic well-being); (2) social insurance programs (contributory interventions to help people better manage risks), and (3) labor market programs to insure individuals against unemployment risks and improve job search prospects.

Social safety nets Noncontributory transfer programs financed by general government revenue.

Stock-flow adjustments Change in the gross debt explained by factors other than the overall fiscal balance (for example, valuation changes).

Stranded assets[1] Assets exposed to devaluations or conversion to 'liabilities' because of unanticipated changes in their initially expected revenues due to innovations and/or evolutions of the business context, including changes in public regulations at the domestic and international levels.

Structural primary balance Extension of the cyclically adjusted primary balance that also corrects for other nonrecurrent effects that go beyond the cycle, such as one-off operations and other factors whose cyclical fluctuations do not coincide with the output cycle (for instance, asset and commodity prices and output composition effects).

Sustainable Development Goals A collection of 17 goals set by the United Nations General Assembly in 2015 covering global warming, poverty, health, education, gender equality, water, sanitation, energy, urbanization, environment, and social justice. Each goal has a set of targets to achieve, and in total there are 169 targets.

Tipping point A level of change in system properties beyond which a system reorganizes, often abruptly, and does not return to the initial state even if the drivers of the change are abated. For the climate system, it refers to a critical threshold when global or regional climate changes from one stable state to another stable state.

Tradable performance standards Requirement to meet an emissions-per-unit-of-output performance standard, for example, for the average carbon emissions per kilowatt hour across power generation plants or per ton of steel.

METHODOLOGICAL AND STATISTICAL APPENDIX

This appendix comprises four sections. "Data and Conventions" describes the data and conventions used to calculate economy group composites. "Fiscal Policy Assumptions" summarizes the country-specific assumptions underlying the estimates and projections for 2023–28. "Definition and Coverage of Fiscal Data" summarizes the classification of countries in the various groups presented in the *Fiscal Monitor* and details the coverage and accounting practices underlying each country's *Fiscal Monitor* data. Statistical tables on key fiscal variables complete the appendix. Data in these tables have been compiled on the basis of information available through September 29, 2023.

Data and Conventions

Country-specific data and projections for key fiscal variables are based on the October 2023 World Economic Outlook database, unless indicated otherwise, and compiled by the IMF staff. Historical data and projections are based on the information IMF country desk officers gather in the context of their missions and through their ongoing analysis of the evolving situation in each country; data are updated continually as more information becomes available. Structural breaks in data may be adjusted to produce smooth series through splicing and other techniques. IMF staff estimates serve as proxies when complete information is unavailable. As a result, *Fiscal Monitor* data may differ from official data in other sources, including the IMF's *International Financial Statistics* and the *Government Finance Statistics Manual* (GFSM 2014).

Sources for fiscal data and projections not covered by the World Economic Outlook database are listed in the respective tables and figures.

Country classification in the *Fiscal Monitor* divides the world into three major groups: 41 advanced economies, 95 emerging market and middle-income economies, and 59 low-income developing countries. *Fiscal Monitor* tables display 37 advanced economies, 39 emerging market and middle-income economies, and 40 low-income developing countries. The countries in the tables generally represent the largest countries within each group based on the size of their GDP in current US dollars. Data for the full list of economies can be found at https://www.imf.org/external/datamapper/datasets/FM. The seven largest advanced economies as measured by GDP (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) constitute the subgroup of major advanced economies, often referred to as the Group of Seven. The members of the euro area are also distinguished as a subgroup. Composite data shown in the tables for the euro area cover the current members for all years, even though membership has increased over time. Data for most European Union member countries have been revised following their adoption of the updated European System of National and Regional Accounts (ESA 2010). Low-income developing countries are countries that have per capita income levels below a certain threshold (set at $2,700, as of 2016, as measured by the World Bank Atlas method), structural features consistent with limited development and structural transformation, and external financial relationships insufficiently open for the countries to be considered emerging market economies. Emerging market and middle-income economies include those not classified as advanced economies or low-income developing countries. See Table A, "Economy Groupings," for more details.

Most fiscal data for advanced economies refer to the general government, whereas data for emerging market and developing economies often refer to only the central government or the budgetary central government (for specific details, see Tables B–D). All fiscal data refer to calendar years, except in the cases of The Bahamas, Bangladesh, Barbados, Bhutan, Botswana, Dominica, Egypt, Eswatini, Ethiopia, Fiji, Haiti, Hong Kong Special Administrative Region, India, the Islamic Republic of Iran, Jamaica, Lesotho, Malawi, the Marshall Islands, Mauritius, Micronesia, Myanmar, Namibia, Nauru, Nepal, Pakistan, Palau, Puerto Rico, Rwanda, Samoa, Singapore, St. Lucia, Thailand, Tonga, and Trinidad and Tobago, for which they refer to the fiscal year. For economies whose fiscal years end before June 30, data are recorded in the previous calendar year. For economies whose fiscal years end on or after June 30, data are recorded in the current calendar year.

Composite data for country groups are weighted averages of individual-country data, unless specified otherwise. Data are weighted by annual nominal GDP converted to US dollars at average market exchange rates as a share of the group GDP.

For the purpose of data reporting in the *Fiscal Monitor*, the Group of Twenty member aggregate refers to the 19 country members and does not include the European Union.

In most advanced economies, and in some large emerging market and middle-income economies, fiscal data follow the GFSM 2014 or are produced using a national accounts methodology that follows the 2008 System of National Accounts (SNA) or ESA 2010, both broadly aligned with the GFSM 2014. Most other countries follow the GFSM 2001, but some countries, including a significant proportion of low-income developing countries, have fiscal data based on the GFSM 1986. The overall fiscal balance refers to net lending and borrowing by the general government. In some cases, however, the overall balance refers to total revenue and grants minus total expenditure and net lending.

The fiscal gross and net debt data reported in the *Fiscal Monitor* are drawn from official data sources and IMF staff estimates. Whereas attempts are made to align gross and net debt data with the definitions in the GFSM, data limitations or specific country circumstances can cause these data to deviate from the formal definitions. Although every effort is made to ensure the debt data are relevant and internationally comparable, differences in both sectoral and instrument coverage mean that the data are not universally comparable. As more information becomes available, changes in either data sources or instrument coverage can give rise to data revisions that are sometimes substantial.

As used in the *Fiscal Monitor*, the term “country” does not always refer to a territorial entity that is a state as understood by international law and practice. As used here, “country” also covers some territorial entities that are not states but whose statistical data are maintained separately and independently.

Australia: For cross-economy comparability, gross and net debt levels reported by national statistical agencies for economies that have adopted the 2008 SNA (Australia, Canada, Hong Kong Special Administrative Region, and the United States) are adjusted to exclude the unfunded pension liabilities of government employees defined-benefit pension plans.

Bangladesh: Data are on a fiscal year basis.

Brazil: The Brazil team is transitioning to GFSM 2014, with adjustments for the period 2001–2009. Municipalities’ primary balances follow below-the-line borrowing requirements from 2001 to 2022. Accrual data for non-interest revenues are not available. Gross public debt includes the Treasury bills on the central bank’s balance sheet, including those not used under repurchase agreements. Net public debt consolidates nonfinancial public sector and central bank debt. The authorities’ definition of general government gross debt excludes government securities held by the central bank, except the stock of Treasury securities the central bank uses for monetary policy (those pledged as security reverse repurchase agreement operations). According to the authorities’ definition, gross debt amounted to 72.9 percent of GDP at the end of 2022.

Canada: For cross-economy comparability, gross and net debt levels reported by national statistical agencies for economies that have adopted the 2008 SNA (Australia, Canada, Hong Kong Special Administrative Region, and the United States) are adjusted to exclude unfunded pension liabilities of government employees, defined-benefit pension plans. Canada’s net debt corresponds to net financial liabilities as reported by Statistics Canada and includes equity and investment fund shares, which Canada has built up substantially. Statistics Canada has made a recent methodological change to value assets at market value instead of book value, which has decreased net debt.

Chile: Cyclically adjusted balances refer to the structural balance, which includes adjustments for output and commodity price developments.

China: Deficit and public debt numbers cover a narrower perimeter of the general government than IMF staff estimates in China Article IV reports (see IMF 2023 for a reconciliation of the two estimates). Public debt data include central government debt as reported by the Ministry of Finance, explicit local government debt, and shares of contingent liabilities the government may incur, based on estimates from the National Audit Office estimate.

IMF staff estimates exclude central government debt issued for China Railway. Relative to the authorities' definition, consolidated general government net borrowing excludes transfers to and from stabilization funds but includes state-administered funds, state-owned enterprise funds, and social security contributions and expenses as well as some off-budget spending by local governments. Deficit numbers do not include some expenditure items, mostly infrastructure investment financed off budget through land sales and local government financing vehicles. Fiscal balances are not consistent with reported debt because no time series of data in line with the National Audit Office debt definition is published officially.

Colombia: Gross public debt refers to the combined public sector, including Ecopetrol and excluding Banco de la República's outstanding external debt.

Dominican Republic: The fiscal series have the following coverage: The public debt, debt service, and cyclically adjusted or structural balances are for the consolidated public sector (which includes the central government, the rest of the nonfinancial public sector, and the central bank). The remaining fiscal series are for the central government.

Egypt: Data are on a fiscal year basis.

Ethiopia: Data are on a fiscal year basis. Gross debt refers to the nonfinancial public sector, excluding Ethiopian Airlines.

Fiji: Data are on a fiscal year basis.

Greece: General government gross debt follows the GFSM 2014 definition and includes the stock of deferred interest.

Haiti: Data are on a fiscal year basis.

Hong Kong Special Administrative Region: Data are on a fiscal year basis. Cyclically adjusted balances include adjustments for land revenue and investment income. For cross-economy comparability, gross and net debt levels reported by national statistical agencies for economies that have adopted the 2008 SNA (Australia, Canada, Hong Kong Special Administrative Region, and the United States) are adjusted to exclude the unfunded pension liabilities of government employees defined-benefit pension plans.

Iceland: Gross debt excludes insurance technical reserves (including pension liabilities) and other accounts payable.

India: Data are on a fiscal year basis.

Islamic Republic of Iran: Data are on a fiscal year basis.

Ireland: For 2015, if the conversion of the government's remaining preference shares to ordinary shares in one bank is excluded, then the fiscal balance is –1.1 percent of GDP. Cyclically adjusted balances reported in Tables A3 and A4 exclude financial sector support measures. Ireland's 2015 national accounts were revised as a result of restructuring and relocation of multinational companies, which resulted in a level shift of nominal and real GDP. For more information, see "National Income and Expenditure Annual Results: 2015," http://www.cso.ie/en/releasesandpublications/er/nie/nationalincomeandexpenditureannualresults2015/.

Japan: Gross debt is on an unconsolidated basis.

Mexico: General government refers to the central government, social security funds, public enterprises, development banks, the national insurance corporation, and the National Infrastructure Fund but excludes subnational governments.

Myanmar: Data are on a fiscal year basis.

Nepal: Data are on a fiscal year basis.

Norway: Cyclically adjusted balances correspond to the cyclically adjusted non-oil overall or primary balance. These variables are a percentage of non-oil potential GDP.

Pakistan: Data are on a fiscal year basis.

Peru: Cyclically adjusted balances include adjustments for commodity price developments.

Singapore: Data are on a fiscal year basis.

Spain: Overall and primary balances include financial sector support measures estimated to be 0.3 percent of GDP for 2013, 0.1 percent of GDP for 2014, 0.1 percent of GDP for 2015, and 0.2 percent of GDP for 2016.

Sweden: Cyclically adjusted balances account for output and employment gaps.

Switzerland: Data submissions at the cantonal and commune levels may be subject to sizable revisions. Cyclically adjusted balances include adjustments for extraordinary operations related to the banking sector.

Thailand: Data are on a fiscal year basis.

Türkiye: Projections in the *Fiscal Monitor* are based on the IMF-defined fiscal balance, which excludes some revenue and expenditure items included in the authorities' headline balance.

Turkmenistan: IMF staff estimates and projections of the fiscal balance exclude receipts from domestic bond issuances as well as privatization operations in line with GFSM 2014. The authorities' official estimates, which are compiled using domestic statistical methodologies, include bond issuance and privatization proceeds as part of government revenues.

United States: For cross-economy comparability, expenditures and fiscal balances are adjusted to exclude the imputed interest on unfunded pension liabilities and the imputed compensation of employees, which are counted as expenditures under the 2008 SNA adopted by the United States. Data for the United States may thus differ from data published by the US Bureau of Economic Analysis. In addition, gross and net debt levels reported by the Bureau of Economic Analysis and national statistical agencies for other economies that have adopted the 2008 SNA (Australia, Canada, and Hong Kong Special Administrative Region) are adjusted to exclude the unfunded pension liabilities of government employees defined-benefit pension plans.

Uruguay: Starting in October 2018, Uruguay's public pension system has been receiving transfers in the context of a new law that compensates persons affected by the creation of the mixed pension system. These funds are recorded as revenues, consistent with the IMF's methodology. Therefore, data and projections for 2018–22 are affected by these transfers, which amounted to 1.2 percent of GDP in 2018, 1.1 percent of GDP in 2019, 0.6 percent of GDP in 2020, and 0.3 percent of GDP in 2021 and are projected to be 0.1 percent of GDP in 2022 and 0 percent thereafter. See IMF Country Report 19/64 for further details. The disclaimer about the public pension system applies only to the revenues and net lending/borrowing series. The coverage of the fiscal data for Uruguay was changed from consolidated public sector to nonfinancial public sector with the October 2019 *World Economic Outlook*. In Uruguay, nonfinancial public sector coverage includes central government, local government, social security funds, nonfinancial public corporations, and Banco de Seguros del Estado. Historical data were also revised accordingly. Under this narrower fiscal perimeter—which excludes the central bank—assets and liabilities held by the nonfinancial public sector where the counterpart is the central bank are not netted out in debt figures. In this context, capitalization bonds issued in the past by the government to the central bank are now part of the nonfinancial public sector debt. Gross and net debt estimates for 2008–11 are preliminary.

Venezuela: Fiscal accounts include the budgetary central government, social security funds, FOGADE (insurance deposit institution), and a sample of public enterprises, including Petróleos de Venezuela, S.A. (PDVSA). Data for 2018–22 are IMF staff estimates.

Fiscal Policy Assumptions

Historical data and projections of key fiscal aggregates are in line with those of the October 2023 *World Economic Outlook*, unless noted otherwise. For underlying assumptions other than on fiscal policy, see the October 2023 *World Economic Outlook*.

Short-term fiscal policy assumptions are based on officially announced budgets, adjusted for differences between the national authorities and the IMF staff regarding macroeconomic assumptions and projected fiscal outturns. Medium-term fiscal projections incorporate policy measures judged likely to be implemented. When the IMF staff have insufficient information to assess the authorities' budget intentions and prospects for policy implementation, an unchanged structural primary balance is assumed, unless indicated otherwise.

Afghanistan: All data and projections for 2022–28 are omitted because of an unusually high degree of uncertainty and given that the IMF has paused its engagement with the country due to a lack of clarity within the international community regarding the recognition of a government in Afghanistan.

Algeria: Starting with the October 2022 *Regional Economic Outlook: Middle East and Central Asia*, total government expenditure and net lending/borrowing include policy lending by the government which mostly reflects support to the pension system and other public sector entities.

Argentina: Fiscal projections are based on the available information regarding budget outturn, budget plans, and IMF-supported program targets for the federal government; on fiscal measures announced by the authorities; and on the IMF staff's macroeconomic projections.

Australia: Fiscal projections are based on data from the Australian Bureau of Statistics, the fiscal year (FY)2023/24 budget published by the Commonwealth Government and the respective state/territory governments, and the IMF staff's estimates and projections.

Austria: Fiscal projections are based on the 2023 Stability Programme. The NextGenerationEU fund has also been incorporated.

Belgium: Projections are based on the Belgian Stability Program 2023–26, the 2023 Budgetary Plan, and other available information on the authorities' fiscal plans, with adjustments for the IMF staff's assumptions.

Brazil: Fiscal projections for 2023 reflect the current policy in place.

Cambodia: Historical fiscal and monetary data are from the Cambodian authorities. Projections are based on the IMF staff's assumptions given discussions with the authorities.

Canada: Projections use the baseline forecasts from the Government of Canada's Budget 2023 and the latest provincial budgets. The IMF staff make some adjustments to these forecasts, including those for differences in macroeconomic projections. The IMF staff's forecast also incorporates the most recent data releases from Statistics Canada's National Economic Accounts, including quarterly federal, provincial, and territorial budgetary outturns.

Chile: Projections are based on the authorities' budget projections, adjusted to reflect the IMF staff's projections for GDP, copper prices, depreciation, and inflation.

China: The IMF staff's fiscal projections incorporate the 2023 budget as well as estimates of off-budget financing.

Colombia: Projections are based on the authorities' policies and projections reflected in the 2023 Financing Plan and the 2023–2034 Medium-Term Fiscal Framework, adjusted to reflect the IMF staff's macroeconomic assumptions.

Croatia: Projections are based on macro framework and authorities' medium-term fiscal guidelines.

Cyprus: Projections are based on the IMF staff's assessment of authorities' budget plans and the IMF staff's macroeconomic assumptions.

Czech Republic: The fiscal projections are based on the authorities' latest-available convergence program, budget and medium-term fiscal framework as well as the IMF staff's macroeconomic framework. Structural balances are net of temporary fluctuations in some revenues and one-offs. COVID-19–related one-offs are, however, included.

Denmark: Estimates for the current year are aligned with the latest official budget numbers, adjusted where appropriate for the IMF staff's macroeconomic assumptions. Beyond the current year, the projections incorporate key features of the medium-term fiscal plan as embodied in the authorities' latest budget. Structural balances are net of temporary fluctuations in some revenues (for example, North Sea revenue, pension yield tax revenue) and one-offs (COVID-19–related one-offs are, however, included).

Egypt: Fiscal projections are mainly based on budget sector operations. Projections are based on the budget for FY2022/23 and the IMF's macroeconomic outlook.

Estonia: The forecast incorporates the authorities' Budget for 2023, adopted tax changes, recent developments, and staff's macroeconomic assumptions.

Finland: Fiscal projections are based on the authorities' projections which reflect their latest medium-term fiscal plan, adjusting where appropriate for the IMF staff's macroeconomic and other assumptions.

France: Projections for 2023 onward are based on the 2018–23 budget laws, the 2023 amending social security finance bill, Stability Program 2023–27, the draft medium-term programming bill, and other available information on the authorities' fiscal plans, adjusted for differences in revenue projections and assumptions on macroeconomic and financial variables.

Ghana: Government debt and interest rate projections are based on a pre-debt restructuring scenario.

Germany: The IMF staff's projections for 2023 and beyond are based on the 2023 budget, the 2023 Stability Programme, the draft 2024 federal budget, the federal government's medium-term budget plan, and data updates from the national statistical agency (Destatis) and the ministry of finance, adjusted for differences in the IMF staff's macroeconomic framework and assumptions concerning revenue elasticities.

Greece: Data since 2010 reflect adjustments in line with the primary balance definition under the enhanced surveillance framework for Greece.

Hong Kong Special Administrative Region: Projections are based on the authorities' medium-term fiscal projections for expenditures.

Hungary: Fiscal projections include the IMF staff's projections of the macroeconomic framework and fiscal policy plans announced in the 2023 and 2024 budgets.

India: Projections are based on available information on the authorities' fiscal plans, with adjustments for the IMF staff's assumptions. Data for states are incorporated with a lag of up to one year. General government data do not include local government, though available estimates suggest the effect of this on the fiscal deficit and debt is small. IMF and Indian presentations differ, particularly regarding disinvestment and license-auction proceeds, net versus gross recording of revenues in certain minor categories, and some public sector lending. Starting with FY2020/21 data, expenditure also includes the off-budget component of food subsidies, consistent with the revised treatment of food subsidies in the budget. The IMF staff adjust expenditure to take out payments for previous years' food subsidies, which are included as expenditure in budget estimates for FY2020/21.

Indonesia: The IMF staff's projections are based on maintaining a neutral fiscal stance going forward, accompanied by moderate tax policy and administration reforms, some expenditure realization, and a gradual increase in capital spending over the medium term in line with fiscal space.

Ireland: Fiscal projections are based on the country's Budget 2023.

Italy: The IMF staff's estimates and projections are informed by the fiscal plans included in the government's 2023 budget, 2023 Economic and Financial Document, and their amendments. The stock of maturing postal bonds is included in the debt projections. The data and forecasts reflect information available through September 21, 2023.

Japan: The projections reflect fiscal measures the government has already announced, with adjustments for the IMF staff's assumptions.

Kazakhstan: Fiscal projections are based on the budget law and the IMF staff's projections.

Korea: The forecast incorporates the 2023 budget and authorities' medium-term fiscal plan as well as the IMF staff's adjustments.

Lebanon: Data and projections for 2023–28 are omitted owing to an unusually high degree of uncertainty.

Libya: The IMF staff's judgments are based on 2022 fiscal accounts.

Malaysia: Fiscal projections are based on budget numbers, discussion with the authorities, and IMF staff estimates.

Mali: Fiscal projections are based on approved budget and IMF staff estimates for past and current year, authorities' medium-term fiscal framework, and IMF staff estimates for outer years.

Malta: Projections are based on the authorities' latest budget document, adjusted for the IMF staff's macroeconomic and other assumptions.

Mexico: The 2020 public sector borrowing requirements estimated by the IMF staff adjust for some statistical discrepancies between above-the-line and below-the-line numbers. Fiscal projections for 2023 and 2024 are informed by the estimates in Criterios 2024; projections for 2025 onward assume continued compliance with rules established in the Federal Budget and Fiscal Responsibility Law.

Moldova: Fiscal projections are based on various bases and growth rates for GDP, consumption, imports, wages, and energy prices and on demographic changes.

Myanmar: Fiscal projections are made based on budget numbers and changed macro environment.

The Netherlands: Fiscal projections for 2023–28 are based on the IMF staff's forecast framework and are also informed by the authorities' draft budget plan and Bureau for Economic Policy Analysis projections.

New Zealand: Fiscal projections are based on the FY2023/24 budget (May 2023) and the IMF staff's estimates.

Nicaragua: Fiscal projections use the latest forecast from Nicaragua's Finance Ministry and the IMF staff's assumptions.

Niger: Fiscal data contain outturns as of the end of 2022. Fiscal sector projections are based on the 2023 budget, discussions with the authorities, as well as the recent political events.

Nigeria: Fiscal projections are based on macro framework reflecting the authorities' recent reforms, as well as the 2023 budget.

Norway: The fiscal projections are based on the 2023 budget and subsequent ad hoc updates.

Philippines: Revenue projections reflect the IMF staff's macroeconomic assumptions and incorporate the updated data. Expenditure projections are based on budgeted figures, institutional arrangements, and current data in each year.

Poland: Data are based on ESA-95 2004 and prior. Data are based on ESA 2010 beginning in 2005 (accrual basis). Projections begin in 2023, based on the 2023 budgets and subsequently announced fiscal measures.

Portugal: The projections for the current year are based on the authorities' approved budget, adjusted to reflect the IMF staff's macroeconomic forecast. Projections thereafter are based on the assumption of unchanged policies. Projections for 2023 reflect information available in the 2023 budget proposal.

Romania: Fiscal projections reflect legislated changes up to the end of 2022 and measures announced in 2023. Medium-term projections include assumptions about gradual implementation of measures and disbursement in the framework of the European Union's Recovery and Resilience Facility.

Russian Federation: The fiscal rule was suspended last year by the government in response to the sanctions imposed after the invasion of Ukraine, allowing for windfall oil and gas revenues above benchmark to be used to finance a larger deficit in 2022. Savings accumulated in the National Welfare Fund can also now be used in this way. A new fiscal rule will become fully effective in 2025. The new rule allows for higher oil and gas revenues to be spent, but it simultaneously targets a smaller primary structural deficit.

Saudi Arabia: The IMF staff's baseline fiscal projections are primarily based on its understanding of government policies as outlined in the 2023 budget statement. Export oil revenues are based on *World Economic Outlook* baseline oil price assumptions and the IMF staff's understanding of current oil policy under the OPEC+ (Organization of the Petroleum Exporting Countries, including Russia and other non-OPEC oil exporters) agreement.

Singapore: FY2021 figures are based on budget execution. FY2022 projections are based on revised figures based on budget execution through the end of 2022. FY2023 projections are based on the initial budget of February 14, 2023. The IMF staff's revenue projections include (1) an increase in the Goods and Services Tax from 7 percent to 8 percent on January 1, 2023, and to 9 percent on January 1, 2024; and (2) an increase of the carbon tax from S$5 per ton to S$25 per ton in 2024 and 2025 and S$45 per ton in 2026 and 2027.

Slovak Republic: The fiscal projection is based on the 2023 Stability Program and takes into consideration available data for 2022.

Spain: Fiscal projections from 2023 onward assume energy support measures amounting to 1 percent of GDP in 2023. Projections reflect disbursements under the European Union's Recovery and Resilience Facility.

Sri Lanka: Fiscal projections are based on the IMF staff's judgment.

Sudan: Projections reflect the IMF staff's analysis based on the assumption that the conflict will end by end-2023.

Sweden: Fiscal estimates are based on the authorities' budget projections and adjusted to reflect the IMF's staff's macroeconomic forecasts.

Switzerland: The projections assume that fiscal policy is adjusted as necessary to keep fiscal balances in line with the requirements of Switzerland's fiscal rules.

Türkiye: The basis for the projections is the IMF-defined fiscal balance, which excludes some revenue and expenditure items that are included in the authorities' headline balance.

United Kingdom: Fiscal projections are based on the March 2023 forecast from the Office for Budget Responsibility (OBR) and the September 2023 release on public sector finances from the Office of National Statistics. IMF projections take the OBR forecast as a reference and overlay adjustments (for differences in assumptions) to both revenues and expenditures. IMF forecasts do not necessarily assume that the new fiscal rules announced on November 17, 2022, will be met at the end of the forecast period. Data are presented on a calendar year basis. Projections do not incorporate the significant upward statistical revisions to 2020 and 2021 GDP that were previewed on September 1, 2023 (with a release date of September 29, 2023).

United States: Fiscal projections are based on the May 2023 Congressional Budget Office baseline and the latest treasury monthly statement, adjusted for the IMF staff's policy and macroeconomic assumptions. Projections incorporate the effects of the Fiscal Responsibility Act. Fiscal projections are adjusted to reflect the IMF staff's forecasts for key macroeconomic and financial variables and different accounting treatment of financial sector support and of defined-benefit pension plans and are converted to a general government basis.

Uruguay: Historical fiscal and monetary data are from the Uruguayan authorities. Projections are based on the authorities' policies and projections, adjusted to reflect IMF staff's macroeconomic assumptions and assessment of policy plans.

Venezuela: Projections for 2023–28 are omitted due to an unusual high degree of uncertainty.

Vietnam: Projections starting 2022 use authorities' 2022 budget numbers and the IMF staff's own projections.

Yemen: Hydrocarbon revenue projection are based on *World Economic Outlook* assumptions for hydrocarbon prices and authorities' projections for oil and gas production. Non-hydrocarbon revenues largely reflect authorities' projection and the evolution of other key indicators. Over the medium term, we assume conflict resolution, a recovery in economic activity, and additional expenditures associated with reconstruction costs.

Zambia: Government net and gross debt projections for 2023–28 are omitted due to debt restructuring.

Definition and Coverage of Fiscal Data

Table A. Economy Groupings

The following groupings of economies are used in the *Fiscal Monitor*. Data for all the economies can be found at https://www.imf.org/external/datamapper/datasets/FM.

Advanced Economies	Emerging Market and Middle-Income Economies	Low-Income Developing Countries	G7 Countries	G20 Countries[1]	Advanced G20 Countries[1]	Emerging G20 Countries
Andorra	Albania	Afghanistan	Canada	Argentina	Australia	Argentina
Australia	Algeria	Bangladesh	France	Australia	Canada	Brazil
Austria	Angola	Benin	Germany	Brazil	France	China
Belgium	Antigua and Barbuda	Bhutan	Italy	Canada	Germany	India
Canada	Argentina	Burkina Faso	Japan	China	Italy	Indonesia
Croatia	Armenia	Burundi	United Kingdom	France	Japan	Mexico
Cyprus	Aruba	Cambodia	United States	Germany	Korea	Russian Federation
Czech Republic	Azerbaijan	Cameroon		India	United Kingdom	Saudi Arabia
Denmark	Bahamas, The	Central African Republic		Indonesia	United States	South Africa
Estonia	Bahrain	Chad		Italy		Türkiye
Finland	Barbados	Comoros		Japan		
France	Belarus	Congo, Democratic Republic of the		Korea		
Germany	Belize	Congo, Republic of		Mexico		
Greece	Bolivia	Côte d'Ivoire		Russian Federation		
Hong Kong SAR	Bosnia and Herzegovina	Djibouti		Saudi Arabia		
Iceland	Botswana	Eritrea		South Africa		
Ireland	Brazil	Ethiopia		Türkiye		
Israel	Brunei Darussalam	Gambia, The		United Kingdom		
Italy	Bulgaria	Ghana		United States		
Japan	Cabo Verde	Guinea				
Korea	Chile	Guinea-Bissau				
Latvia	China	Haiti				
Lithuania	Colombia	Honduras				
Luxembourg	Costa Rica	Kenya				
Macao SAR	Dominica	Kiribati				
Malta	Dominican Republic	Kyrgyz Republic				
Netherlands, The	Ecuador	Lao P.D.R.				
New Zealand	Egypt	Lesotho				
Norway	El Salvador	Liberia				
Portugal	Equatorial Guinea	Madagascar				
Puerto Rico	Eswatini	Malawi				
San Marino	Fiji	Mali				
Singapore	Gabon	Mauritania				
Slovak Republic	Georgia	Moldova				
Slovenia	Grenada	Mozambique				
Spain	Guatemala	Myanmar				
Sweden	Guyana	Nepal				
Switzerland	Hungary	Nicaragua				
Taiwan Province of China	India	Niger				
United Kingdom	Indonesia	Nigeria				
United States	Iran	Papua New Guinea				
	Iraq	Rwanda				
	Jamaica	São Tomé and Príncipe				
	Jordan	Senegal				
	Kazakhstan	Sierra Leone				
	Kosovo	Solomon Islands				
	Kuwait	South Sudan				
	Lebanon	Somalia				
	Libya	Sudan				
	Malaysia	Tajikistan				

Table A. Economy Groupings *(continued)*

Advanced Economies	Emerging Market and Middle-Income Economies	Low-Income Developing Countries	G7 Countries	G20 Countries[1]	Advanced G20 Countries[1]	Emerging G20 Countries
	Maldives	Tanzania				
	Marshall Islands	Timor-Leste				
	Mauritius	Togo				
	Mexico	Uganda				
	Micronesia	Uzbekistan				
	Mongolia	Vietnam				
	Montenegro	Yemen				
	Morocco	Zambia				
	Namibia	Zimbabwe				
	Nauru					
	North Macedonia					
	Oman					
	Pakistan					
	Palau					
	Panama					
	Paraguay					
	Peru					
	Philippines					
	Poland					
	Qatar					
	Romania					
	Russian Federation					
	Samoa					
	Saudi Arabia					
	Serbia					
	Seychelles					
	South Africa					
	Sri Lanka					
	St. Kitts and Nevis					
	St. Lucia					
	St. Vincent and the Grenadines					
	Suriname					
	Thailand					
	Tonga					
	Trinidad and Tobago					
	Tunisia					
	Türkiye					
	Turkmenistan					
	Tuvalu					
	Ukraine					
	United Arab Emirates					
	Uruguay					
	Vanuatu					
	Venezuela					
	West Bank and Gaza					

Note: G7 = Group of Seven; G20 = Group of Twenty.
[1] Does not include European Union aggregate.

Table A. Economy Groupings *(continued)*

Euro Area	Emerging Market and Middle-Income Asia	Emerging Market and Middle-Income Europe	Emerging Market and Middle-Income Latin America	Emerging Market and Middle-Income Middle East, North Africa, and Pakistan	Emerging Market and Middle-Income Africa
Austria	Brunei Darussalam	Albania	Antigua and Barbuda	Algeria	Angola
Belgium	China	Azerbaijan	Argentina	Bahrain	South Africa
Croatia	Fiji	Belarus	Aruba	Egypt	
Cyprus	India	Bosnia and Herzegovina	Bahamas, The	Iran	
Estonia	Indonesia	Bulgaria	Barbados	Iraq	
Finland	Malaysia	Hungary	Belize	Jordan	
France	Maldives	Kazakhstan	Bolivia	Kuwait	
Germany	Marshall Islands	Kosovo	Brazil	Lebanon	
Greece	Micronesia	Montenegro	Chile	Libya	
Ireland	Mongolia	North Macedonia	Colombia	Morocco	
Italy	Nauru	Poland	Costa Rica	Oman	
Latvia	Palau	Romania	Dominica	Pakistan	
Lithuania	Philippines	Russian Federation	Dominican Republic	Qatar	
Luxembourg	Samoa	Serbia	Ecuador	Saudi Arabia	
Malta	Sri Lanka	Türkiye	El Salvador	Tunisia	
Netherlands	Thailand	Ukraine	Grenada	United Arab Emirates	
Portugal	Tonga		Guatemala		
Slovak Republic	Tuvalu		Guyana		
Slovenia	Vanuatu		Jamaica		
Spain			Mexico		
			Panama		
			Paraguay		
			Peru		
			St. Kitts and Nevis		
			St. Lucia		
			St. Vincent and the Grenadines		
			Suriname		
			Trinidad and Tobago		
			Uruguay		
			Venezuela		

Table A. Economy Groupings *(continued)*

Low-Income Developing Asia	Low-Income Developing Latin America	Low-Income Developing Sub-Saharan Africa	Low-Income Developing Others	Low-Income Oil Producers	Oil Producers
Bangladesh	Haiti	Benin	Afghanistan	Chad	Algeria
Bhutan	Honduras	Burkina Faso	Djibouti	Congo, Republic of	Angola
Cambodia	Nicaragua	Burundi	Kyrgyz Republic	Nigeria	Azerbaijan
Kiribati		Cameroon	Mauritania	Timor-Leste	Bahrain
Lao P.D.R.		Central African Republic	Moldova	Yemen	Brunei Darussalam
Myanmar		Chad	Somalia		Chad
Nepal		Comoros	Sudan		Canada
Papua New Guinea		Congo, Democratic Republic of the	Tajikistan		Congo, Republic of
Solomon Islands		Congo, Republic of	Uzbekistan		Ecuador
Timor-Leste		Côte d'Ivoire	Yemen		Equatorial Guinea
Vietnam		Eritrea			Gabon
		Ethiopia			Iran
		Gambia, The			Iraq
		Ghana			Kazakhstan
		Guinea			Kuwait
		Guinea-Bissau			Libya
		Kenya			Nigeria
		Lesotho			Norway
		Liberia			Oman
		Madagascar			Qatar
		Malawi			Russian Federation
		Mali			Saudi Arabia
		Mozambique			Timor-Leste
		Niger			Trinidad and Tobago
		Nigeria			Turkmenistan
		Rwanda			United Arab Emirates
		São Tomé and Príncipe			Venezuela
		Senegal			Yemen
		Sierra Leone			
		South Sudan			
		Tanzania			
		Togo			
		Uganda			
		Zambia			
		Zimbabwe			

Table B. Advanced Economies: Definition and Coverage of *Fiscal Monitor* Data

	Overall Fiscal Balance[1]			Cyclically Adjusted Balance			Gross Debt		
	Coverage		Accounting Practice	Coverage		Accounting Practice	Coverage		Valuation of Debt[2]
	Aggregate	Subsectors		Aggregate	Subsectors		Aggregate	Subsectors	
Andorra	GG	CG,LG,SS	A	. . .	. . .	. . .	GG	CG	Nominal
Australia	GG	CG,SG,LG,TG	A	GG	CG,SG,LG,TG	A	GG	CG,SG,LG,TG	Current market
Austria	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	Face
Belgium	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	Face
Canada	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	Face
Croatia	GG	CG,LG	A	GG	CG,LG	A	GG	CG,LG	Nominal
Cyprus	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Face
Czech Republic	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Nominal
Denmark	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Face
Estonia	GG	CG,LG,SS	C	. . .	. . .	. . .	GG	CG,LG,SS	Nominal
Finland	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Face
France	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Face
Germany	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	Face
Greece	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Nominal
Hong Kong SAR	GG	CG	C	GG	CG	C	GG	CG	Face
Iceland	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Face
Ireland	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Nominal
Israel	GG	CG,LG,SS	Mixed	GG	CG,LG,SS	Mixed	GG	CG,LG,SS	Nominal
Italy	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Face
Japan	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Current market
Korea	CG	CG,SS	C	CG	CG,SS	C	GG	CG,SS	Nominal
Latvia	GG	CG,LG,SS	C	GG	CG,LG,SS	C	GG	CG,LG,SS	Nominal
Lithuania	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Nominal
Luxembourg	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Face
Malta	GG	CG,SS	A	GG	CG,SS	A	GG	CG,SS	Nominal
The Netherlands	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Nominal
New Zealand	GG	CG,LG	A	GG	CG,LG	A	GG	CG,LG	Current market
Norway	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Current market
Portugal	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Nominal
Singapore	GG	CG	C	GG	CG	C	GG	CG	Nominal
Slovak Republic	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Face
Slovenia	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Face
Spain	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	Nominal
Sweden	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Nominal
Switzerland	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	A	GG	CG,SG,LG,SS	Nominal
United Kingdom	GG	CG,LG	A	GG	CG,LG	A	GG	CG,LG	Nominal
United States	GG	CG,SG,LG	A	GG	CG,SG,LG	A	GG	CG,SG,LG	Nominal

Note: Coverage: CG = central government; GG = general government; LG = local governments; SG = state governments; SS = social security funds; TG = territorial governments. Accounting practice: A = accrual; C = cash; Mixed = combination of accrual and cash accounting.

[1] In many economies, fiscal data follow the IMF's *Government Finance Statistics Manual 2014*. The concept of overall fiscal balance refers to net lending and borrowing of the general government. In some cases, however, the overall balance refers to total revenue and grants minus total expenditure and net lending.

[2] "Nominal" refers to debt securities that are valued at their nominal values; that is, the nominal value of a debt instrument at any moment in time is the amount that the debtor owes to the creditor. "Face" refers to the undiscounted amount of principal to be repaid at (or before) maturity. The use of face value as a proxy for nominal value in measuring the gross debt position can result in an inconsistent approach across all instruments and is not recommended unless nominal and market values are not available. "Current market" refers to debt securities that are valued at market prices; insurance, pension, and standardized guarantee schemes are valued according to principles that are equivalent to market valuation; and all other debt instruments are valued at nominal prices, which are considered to be the best generally available proxies for their market prices.

Table C. Emerging Market and Middle-Income Economies: Definition and Coverage of *Fiscal Monitor* Data

	Overall Fiscal Balance[1]			Cyclically Adjusted Balance			Gross Debt		
	Coverage		Accounting Practice	Coverage		Accounting Practice	Coverage		Valuation of Debt[2]
	Aggregate	Subsectors		Aggregate	Subsectors		Aggregate	Subsectors	
Algeria	CG	CG	C	. . .	. . .	. . .	CG	CG	Face
Angola[3]	GG	CG,LG	Mixed	. . .	. . .	. . .	GG	CG,LG	Nominal
Argentina	GG	CG,SG,SS	C	CG	CG	C	CG	CG	Nominal
Belarus[4]	GG	CG,LG,SS	C	. . .	. . .	. . .	GG	CG,LG,SS	Nominal
Brazil	GG	CG,SG,LG,SS	C	GG	CG,SG,LG,SS	C	GG	CG,SG,LG,SS	Nominal
Bulgaria	GG	CG,LG,SS	C	GG	CG,LG,SS	C	GG	CG,LG,SS	Nominal
Chile	GG	CG,LG	A	CG	CG	A	GG	CG,LG	Face
China	GG	CG,LG,SS	C	GG	CG,LG,SS	C	GG	CG,LG,SS	Face
Colombia[5]	GG	CG,SG,LG,SS	Mixed	GG	CG,SG,LG,SS	Mixed	GG	CG,SG,LG,SS	Face
Dominican Republic	CG	CG,LG,SS,NMPC	Mixed	PS	CG,LG,SS,NMPC	Mixed	PS	CG,LG,SS,NMPC	Face
Ecuador	NFPS	CG,SG,LG,SS,NFPC	Mixed	NFPS	CG,SG,LG,SS,NFPC	Mixed	NFPS	CG,SG,LG,SS,NFPC	Nominal
Egypt	GG	CG,LG,SS	C	GG	CG,LG,SS	C	GG	CG,LG,SS	Nominal
Hungary	GG	CG,LG,SS,NMPC	A	GG	CG,LG,SS,NMPC	A	GG	CG,LG,SS,NMPC	Face
India	GG	CG,SG	C	GG	CG,SG	C	GG	CG,SG	Nominal
Indonesia	GG	CG,LG	C	GG	CG,LG	C	GG	CG,LG	Face
Iran	CG	CG	C	. . .	. . .	. . .	CG	CG	Nominal
Kazakhstan	GG	CG,LG	C	. . .	. . .	. . .	GG	CG,LG	Nominal
Kuwait	GG	CG,SS	Mixed	. . .	. . .	. . .	GG	CG,SS	Nominal
Lebanon	CG	CG	Mixed	CG	CG	Mixed	CG	CG	Nominal
Malaysia	GG	CG,SG,LG	C	GG	CG,SG,LG	C	GG	CG,SG,LG	Nominal
Mexico	PS	CG,SS,NMPC,NFPC	C	PS	CG,SS,NMPC,NFPC	C	PS	CG,SS,NMPC,NFPC	Face
Morocco	CG	CG	A	. . .	. . .	. . .	CG	CG	Face
Oman	CG	CG	C	. . .	. . .	. . .	CG	CG	Nominal
Pakistan	GG	CG,SG,LG	C	. . .	. . .	. . .	GG	CG,SG,LG	Nominal
Peru	GG	CG,SG,LG,SS	C	GG	CG,SG,LG,SS	C	NFPS	CG,SG,LG,SS,NFPC	Face
Philippines	GG	CG,LG,SS	C	GG	CG,LG,SS	C	GG	CG,LG,SS	Nominal
Poland	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Face
Qatar	CG	CG	C	. . .	. . .	. . .	CG	CG	Nominal
Romania	GG	CG,LG,SS	C	GG	CG,LG,SS	C	GG	CG,LG,SS	Face
Russian Federation	GG	CG,SG,SS	Mixed	GG	CG,SG,SS	Mixed	GG	CG,SG,SS	Current market
Saudi Arabia	CG	CG	C	. . .	. . .	. . .	CG	CG	Nominal
South Africa[6]	GG	CG,SG,SS	C	GG	CG,SG,SS	C	GG	CG,SG,SS	Nominal
Sri Lanka	CG	CG	C	. . .	. . .	. . .	CG	CG	Nominal
Thailand[7]	PS	CG,BCG,LG,SS	A	PS	CG,BCG,LG,SS	A	PS	CG,BCG,LG,SS	Nominal
Türkiye	GG	CG,LG,SS	A	GG	CG,LG,SS	A	GG	CG,LG,SS	Nominal
Ukraine	GG	CG,LG,SS	C	GG	CG,LG,SS	C	GG	CG,LG,SS	Nominal
United Arab Emirates	GG	CG,BCG,SG,SS	Mixed	. . .	. . .	. . .	GG	CG,BCG,SG,SS	Nominal
Uruguay	NFPS	CG,LG,SS,NMPC,NFPC	A	. . .	. . .	. . .	NFPS	CG,LG,SS,NMPC,NFPC	Face
Venezuela[8]	GG	BCG,NFPC	C	GG	BCG,NFPC	C	GG	BCG,NFPC	Nominal

Note: Coverage: BCG = budgetary central government; CG = central government; GG = general government; LG = local governments; NFPC = nonfinancial public corporations; NFPS = nonfinancial public sector; NMPC = nonmonetary financial public corporations; PS = public sector; SG = state governments; SS = social security funds. Accounting practice: A = accrual; C = cash; Mixed = combination of accrual and cash accounting.

[1] In many economies, fiscal data follow the IMF's *Government Finance Statistics Manual 2014*. The concept of overall fiscal balance refers to net lending and borrowing of the general government. In some cases, however, the overall balance refers to total revenue and grants minus total expenditure and net lending.

[2] "Nominal" refers to debt securities that are valued at their nominal values; that is, the nominal value of a debt instrument at any moment in time is the amount that the debtor owes to the creditor. "Face" refers to the undiscounted amount of principal to be repaid at (or before) maturity. The use of face value as a proxy for nominal value in measuring the gross debt position can result in an inconsistent approach across all instruments and is not recommended unless nominal and market values are not available. "Current market" refers to debt securities that are valued at market prices; insurance, pension, and standardized guarantee schemes are valued according to principles that are equivalent to market valuation; and all other debt instruments are valued at nominal prices, which are considered to be the best generally available proxies of their market prices.

[3] Gross debt includes the domestic and external debt of the central government; the external debt of the state-owned oil company, Sonangol, and the state-owned airline, TAAG; public guarantees; and reported external liabilities of other state entities, including external arrears.

[4] Gross debt refers to general government public debt, including publicly guaranteed debt.

[5] Revenue is recorded on a cash basis and expenditure on an accrual basis.

[6] Coverage for South Africa is consolidated government, which serves as a good proxy for the general government. It includes the national and provincial governments and certain public entities, while local governments are only partly covered. The subnational government debt is estimated to be limited given the available data from the South African Reserve Bank.

[7] Data for Thailand do not include the debt of specialized financial institutions (SFIs/NMPC) without a government guarantee.

[8] The fiscal accounts include the budgetary central government, social security, FOGADE (an insurance deposit institution), and a sample of public enterprises, including Petróleos de Venezuela, S.A. (PDVSA). Data for 2018–22 are IMF staff estimates.

Table D. Low-Income Developing Countries: Definition and Coverage of *Fiscal Monitor* Data

	Overall Fiscal Balance[1]			Cyclically Adjusted Balance			Gross Debt		
	Coverage		Accounting Practice	Coverage		Accounting Practice	Coverage		Valuation of Debt[2]
	Aggregate	Subsectors		Aggregate	Subsectors		Aggregate	Subsectors	
Afghanistan	CG	CG	C	...	...	...	CG	CG	Nominal
Bangladesh	CG	CG	C	CG	CG	C	CG	CG	Nominal
Benin	CG	CG	C	...	...	...	CG	CG	Nominal
Burkina Faso	CG	CG	CB	...	...	...	CG	CG	Face
Cambodia	CG	CG,LG	A	CG	CG,LG	A	CG	CG,LG	Face
Cameroon	CG	CG	C	...	...	...	CG	CG	Nominal
Chad	NFPS	CG,NFPC	C	...	...	...	CG	CG	Face
Congo, Democratic Republic of the	CG	CG,LG	C	...	...	...	GG	CG,LG,NFPC	Nominal
Congo, Republic of	CG	CG	A	...	...	...	CG	CG	Nominal
Côte d'Ivoire	CG	CG,SS	Mixed	...	...	...	CG	CG,NFPC	Nominal
Ethiopia	GG	CG,SG,LG	C	...	...	...	NFPS	CG,SG,LG,NFPC	Nominal
Ghana	CG	CG	CB	...	...	...	CG	CG	Face
Guinea	CG	CG	Mixed	...	...	...	CG	CG	Nominal
Haiti[3]	CG	CG	C	...	...	...	CG	CG	Nominal
Honduras	GG	CG,LG,SS	Mixed	GG	CG,LG,SS	Mixed	GG	CG,LG,SS	Nominal
Kenya	CG	CG	C	...	...	...	CG	CG	Current market
Kyrgyz Republic	GG	CG,LG,SS	C	...	...	...	GG	CG,LG,SS	Face
Lao P.D.R.[4]	CG	CG	C	CG	CG	C	CG	CG	Nominal
Madagascar	CG	CG,LG	CB	...	...	...	NFPS	CG,LG,NFPC	Nominal
Malawi	CG	CG	C	...	...	...	CG	CG	...
Mali	CG	CG	Mixed	...	...	...	CG	CG	Nominal
Moldova	GG	CG,LG,SS	C	GG	CG,LG,SS	C	GG	CG,LG,SS	Nominal
Mozambique	CG	CG,SG	Mixed	CG	CG,SG	Mixed	CG	CG,SG	Nominal
Myanmar[5]	NFPS	CG,NFPC	C	...	...	...	NFPS	CG,NFPC	Face
Nepal	CG	CG	C	CG	CG	C	CG	CG	Face
Nicaragua	GG	CG,LG,SS	C	GG	CG,LG,SS	C	GG	CG,LG,SS	Nominal
Niger	CG	CG	A	...	...	...	CG	CG	Nominal
Nigeria	GG	CG,SG,LG	C	...	...	...	GG	CG,SG,LG	Current market
Papua New Guinea	CG	CG	C	...	...	...	CG	CG	Face
Rwanda	GG	CG,LG	Mixed	...	...	...	CG	CG	Nominal
Senegal	CG	CG	C	...	...	...	PS	CG,LG,SS,NFPC	Nominal
Sudan	CG	CG	Mixed	...	...	...	CG	CG	Nominal
Tajikistan	GG	CG,LG,SS	C	...	...	...	GG	CG,LG,SS	Nominal
Tanzania	CG	CG,LG	C	...	...	...	CG	CG,LG	Nominal
Uganda	CG	CG	C	...	...	...	CG	CG	Nominal
Uzbekistan[6]	GG	CG,SG,LG,SS	C	...	...	...	GG	CG,SG,LG,SS	Nominal
Vietnam	GG	CG,SG,LG	C	GG	CG,SG,LG	C	GG	CG,SG,LG	Nominal
Yemen	GG	CG,LG	C	...	...	...	GG	CG,LG	Nominal
Zambia	CG	CG	C	...	...	...	CG	CG	Nominal
Zimbabwe	CG	CG	C	...	...	...	CG	CG	Current market

Note: Coverage: CG = central government; GG = general government; LG = local governments; NFPC = nonfinancial public corporations; NFPS = nonfinancial public sector; PS = public sector; SG = state governments; SS = social security funds. Accounting practice: A = accrual; C = cash; CB = commitments based; Mixed = combination of accrual and cash accounting.

[1] In many countries, fiscal data follow the IMF's *Government Finance Statistics Manual 2014*. The concept of overall fiscal balance refers to net lending and borrowing of the general government. In some cases, however, the overall balance refers to total revenue and grants minus total expenditure and net lending.

[2] "Nominal" refers to debt securities that are valued at their nominal values; that is, the nominal value of a debt instrument at any moment in time is the amount that the debtor owes to the creditor. "Face" refers to the undiscounted amount of principal to be repaid at (or before) maturity. The use of face value as a proxy for nominal value in measuring the gross debt position can result in an inconsistent approach across all instruments and is not recommended unless nominal and market values are not available. "Current market" refers to debt securities that are valued at market prices; insurance, pension, and standardized guarantee schemes are valued according to principles that are equivalent to market valuation; and all other debt instruments are valued at nominal prices, which are considered to be the best generally available proxies of their market prices.

[3] Haiti's fiscal balance and debt data cover the central government, special funds and programs (Fonds d'Entretien Routier and Programme de Scolarisation Universelle, Gratuite, et Obligatoire), and the state-owned electricity company EDH.

[4] Lao P.D.R.'s fiscal spending includes capital spending by local governments financed by loans provided by the central bank.

[5] Overall and primary balances in 2012 are based on monetary statistics and are different from the balances calculated from expenditure and revenue data.

[6] Uzbekistan's listing includes the Fund for Reconstruction and Development.

Table A1. Advanced Economies: General Government Overall Balance, 2014–28

(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	–3.1	–2.6	–2.7	–2.4	–2.4	–3.0	–10.2	–7.5	–3.3	–5.2	–4.4	–4.2	–3.9	–3.8	–4.0
Euro Area	–2.5	–1.9	–1.5	–0.9	–0.4	–0.6	–7.1	–5.3	–3.6	–3.4	–2.7	–2.3	–2.1	–2.1	–2.1
G7	–3.6	–3.0	–3.3	–3.3	–3.3	–3.8	–11.6	–9.1	–4.1	–6.5	–5.6	–5.3	–5.0	–4.8	–5.0
G20 Advanced	–3.4	–2.9	–3.1	–3.0	–3.0	–3.6	–11.2	–8.7	–4.0	–6.1	–5.3	–5.0	–4.7	–4.5	–4.7
Andorra	2.1	1.7	4.1	3.3	2.7	2.3	–1.1	–1.2	4.9	3.3	3.4	3.4	3.5	3.7	3.7
Australia	–2.9	–2.8	–2.4	–1.7	–1.3	–4.4	–8.7	–6.5	–2.3	–1.4	–2.2	–1.9	–1.5	–1.5	–1.2
Austria	–2.7	–1.0	–1.5	–0.8	0.2	0.6	–8.0	–5.8	–3.2	–2.4	–2.0	–1.7	–1.6	–1.5	–1.5
Belgium	–3.1	–2.4	–2.4	–0.7	–0.9	–2.0	–9.0	–5.5	–3.9	–4.9	–4.8	–4.8	–5.1	–5.5	–5.5
Canada	0.2	–0.1	–0.5	–0.1	0.4	0.0	–10.9	–4.4	–0.8	–0.7	–0.6	–0.5	–0.4	–0.3	–0.2
Croatia	–5.2	–3.5	–1.0	0.8	0.1	2.2	–7.3	–2.5	0.4	–0.8	–1.7	–1.1	–0.8	–0.8	–0.6
Cyprus[1]	–0.2	0.1	0.3	1.9	–3.6	1.3	–5.8	–2.0	2.1	1.9	1.7	1.5	1.3	1.0	0.9
Czech Republic	–2.1	–0.6	0.7	1.5	0.9	0.3	–5.8	–5.1	–3.6	–4.1	–2.3	–2.0	–1.9	–1.6	–1.4
Denmark	1.1	–1.3	–0.1	1.8	0.8	4.1	0.4	4.1	3.4	1.8	0.9	0.5	0.3	0.1	0.0
Estonia	0.3	–0.4	–1.0	–1.0	–1.1	0.1	–5.5	–2.4	–0.9	–3.9	–3.2	–2.8	–2.7	–2.6	–2.5
Finland	–3.0	–2.4	–1.7	–0.7	–0.9	–0.9	–5.6	–2.8	–0.9	–2.6	–2.5	–2.8	–2.0	–1.3	–1.1
France	–3.9	–3.6	–3.6	–3.0	–2.3	–3.1	–9.0	–6.5	–4.8	–4.9	–4.5	–4.0	–3.6	–3.5	–3.6
Germany	0.6	1.0	1.2	1.3	1.9	1.5	–4.3	–3.6	–2.5	–2.9	–1.7	–0.9	–0.6	–0.5	–0.5
Greece	–4.2	–3.0	0.3	0.9	0.8	0.0	–10.5	–7.7	–2.3	–1.6	–0.8	–0.9	–0.9	–1.1	–1.2
Hong Kong SAR	3.6	0.6	4.4	5.5	2.3	–0.6	–9.2	0.0	–6.6	–3.9	–1.0	0.2	0.6	1.3	1.3
Iceland	0.3	–0.4	12.5	1.0	1.0	–1.6	–8.9	–8.5	–4.1	–0.9	–1.2	–1.3	–0.3	–0.4	–0.9
Ireland[1]	–3.6	–2.0	–0.8	–0.3	0.1	0.5	–5.0	–1.6	1.6	1.7	1.8	1.8	1.6	1.1	0.9
Israel	–2.3	–1.2	–1.7	–1.2	–3.6	–3.9	–10.8	–3.7	0.6	–1.6	–2.0	–2.8	–3.2	–3.5	–3.7
Italy	–3.0	–2.6	–2.4	–2.4	–2.2	–1.5	–9.7	–9.0	–8.0	–5.0	–4.0	–3.3	–2.7	–2.7	–2.5
Japan	–5.6	–3.7	–3.6	–3.1	–2.5	–3.0	–9.1	–6.2	–6.9	–5.6	–3.7	–2.6	–2.7	–2.9	–3.3
Korea	0.6	0.5	1.6	2.2	2.6	0.4	–2.2	0.0	–1.6	–1.2	–0.9	–0.3	–0.2	0.0	0.0
Latvia	–1.7	–1.5	–0.4	–0.8	–0.7	–0.4	–3.7	–5.4	–3.7	–3.7	–1.8	–2.0	–2.0	–1.1	–0.9
Lithuania	–0.7	–0.2	0.3	0.5	0.6	0.3	–7.2	–1.0	–0.6	–1.8	–1.4	–1.1	–1.1	–1.0	–1.0
Luxembourg	1.3	1.3	1.9	1.4	3.0	2.2	–3.4	0.7	0.2	–2.8	–1.9	–1.3	–0.8	–0.7	–0.7
Malta	–1.7	–1.0	1.1	3.3	2.0	0.5	–9.5	–7.7	–5.7	–5.2	–3.9	–3.5	–2.9	–2.2	–1.6
The Netherlands	–2.3	–1.9	0.1	1.4	1.5	1.8	–3.7	–2.3	–0.1	–2.1	–1.9	–2.0	–2.2	–2.4	–2.5
New Zealand	–0.3	0.4	1.0	1.4	1.3	–2.5	–4.4	–3.5	–3.5	–3.4	–3.5	–2.2	–1.3	–0.4	0.0
Norway	8.6	6.0	4.0	5.0	7.8	6.5	–2.6	10.0	25.3	15.1	14.4	13.1	12.0	10.9	9.8
Portugal	–7.3	–4.3	–1.9	–3.0	–0.3	0.1	–5.8	–2.9	–0.4	–0.2	–0.1	–0.2	–0.2	–0.2	–0.2
Singapore	4.6	2.9	3.3	5.2	3.7	3.8	–6.8	1.2	0.8	3.2	2.8	3.4	2.9	2.8	2.7
Slovak Republic	–3.1	–2.7	–2.6	–1.0	–1.0	–1.2	–5.4	–5.4	–2.0	–5.5	–4.4	–4.4	–4.5	–4.0	–3.9
Slovenia	–5.5	–2.8	–1.9	–0.1	0.7	0.7	–7.6	–4.6	–3.1	–3.5	–2.7	–2.3	–1.9	–1.7	–1.7
Spain[1]	–6.1	–5.3	–4.3	–3.1	–2.6	–3.1	–10.1	–6.8	–4.7	–3.9	–3.0	–3.4	–3.4	–3.4	–3.4
Sweden	–1.5	0.0	1.0	1.4	0.8	0.6	–2.8	–0.1	0.7	–0.4	–0.6	0.2	0.4	0.4	0.4
Switzerland	–0.2	0.5	0.2	1.1	1.3	1.3	–3.0	–0.3	0.9	0.1	0.4	0.3	0.2	0.2	0.2
United Kingdom	–5.5	–4.5	–3.3	–2.4	–2.2	–2.2	–13.0	–8.3	–5.5	–4.5	–3.9	–3.7	–3.7	–3.5	–3.5
United States[2]	–4.0	–3.5	–4.4	–4.8	–5.3	–5.7	–14.0	–11.6	–3.7	–8.2	–7.4	–7.4	–7.0	–6.7	–7.0

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: For country-specific details, see “Data and Conventions” in text and Table B.

[1] Data include financial sector support. For Cyprus, 2014 and 2015 balances exclude financial sector support.

[2] For cross-economy comparison, the expenditures and fiscal balances of the United States are adjusted to exclude the imputed interest on unfunded pension liabilities and the imputed compensation of employees, which are counted as expenditures under the 2008 System of National Accounts (2008 SNA) adopted by the United States, but not in economies that have not yet adopted the 2008 SNA. Data for the United States in this table may therefore differ from data published by the US Bureau of Economic Analysis.

Table A2. Advanced Economies: General Government Primary Balance, 2014–28
(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	–1.5	–1.1	–1.1	–1.0	–0.9	–1.6	–9.0	–6.1	–1.6	–3.5	–2.6	–2.2	–1.8	–1.6	–1.6
Euro Area	–0.2	0.1	0.4	0.8	1.2	0.8	–5.7	–4.0	–2.1	–1.9	–1.0	–0.5	–0.2	–0.1	0.0
G7	–1.8	–1.3	–1.6	–1.6	–1.6	–2.1	–10.1	–7.4	–2.1	–4.4	–3.3	–2.9	–2.4	–2.1	–2.1
G20 Advanced	–1.7	–1.3	–1.5	–1.4	–1.4	–2.0	–9.7	–7.0	–2.1	–4.1	–3.1	–2.7	–2.2	–1.9	–2.0
Andorra	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Australia	–2.1	–1.9	–1.5	–0.8	–0.4	–3.6	–7.8	–5.7	–1.4	–0.2	–0.7	–0.3	0.1	0.2	0.5
Austria	–0.7	0.9	0.1	0.6	1.4	1.6	–7.0	–5.1	–2.6	–1.7	–0.8	–0.5	–0.2	–0.1	–0.1
Belgium	–0.2	0.2	0.0	1.4	1.0	–0.3	–7.3	–4.0	–2.6	–3.3	–3.0	–2.8	–3.0	–3.1	–3.0
Canada	0.5	0.6	0.1	0.1	0.5	0.1	–10.5	–5.0	–1.3	–1.0	–0.7	–0.5	–0.3	–0.2	0.0
Croatia	–2.3	–0.4	1.8	3.2	2.2	4.2	–5.5	–1.1	1.6	0.9	0.0	0.4	0.5	0.4	0.5
Cyprus[1]	2.8	3.0	2.7	4.2	–1.4	3.3	–3.7	–0.3	3.5	3.2	3.0	2.7	2.5	2.2	2.2
Czech Republic	–1.0	0.3	1.5	2.1	1.5	0.8	–5.2	–4.5	–3.1	–3.2	–1.2	–1.0	–0.8	–0.6	–0.4
Denmark	1.6	–0.6	0.4	1.7	0.4	3.9	0.1	3.7	3.2	1.4	0.4	0.0	–0.2	–0.3	–0.5
Estonia	0.2	–0.4	–1.0	–1.1	–1.2	0.1	–5.5	–2.5	–0.9	–3.6	–2.9	–2.4	–2.2	–2.2	–2.1
Finland	–2.8	–2.3	–1.4	–0.4	–0.7	–0.8	–5.5	–2.8	–0.9	–2.6	–2.1	–2.1	–1.6	–1.1	–1.0
France	–1.8	–1.8	–1.9	–1.3	–0.7	–1.7	–7.8	–5.2	–3.0	–3.3	–2.7	–2.0	–1.5	–1.1	–0.9
Germany	1.8	2.0	2.1	2.2	2.7	2.1	–3.9	–3.1	–1.9	–2.1	–0.8	0.0	0.3	0.4	0.4
Greece	–0.2	0.6	3.5	4.1	4.2	3.0	–7.5	–5.2	0.1	1.0	2.0	2.0	2.2	2.2	2.2
Hong Kong SAR	3.6	0.6	3.6	4.7	1.0	–2.2	–11.1	–2.7	–9.8	–5.9	–2.4	–1.3	–0.6	0.2	0.2
Iceland	3.8	3.2	15.5	3.9	3.1	0.5	–6.8	–6.3	–0.9	1.4	0.6	0.7	1.5	1.6	1.0
Ireland[1]	–0.3	0.3	1.5	1.6	1.7	1.7	–4.0	–0.8	2.2	2.3	2.4	2.3	2.1	1.6	1.3
Israel	–0.2	0.6	0.2	0.7	–1.4	–2.0	–9.0	–1.0	3.8	1.1	0.4	–0.6	–1.0	–1.3	–1.4
Italy	1.4	1.4	1.3	1.2	1.3	1.7	–6.4	–5.6	–3.8	–1.1	0.0	0.8	1.5	1.5	1.7
Japan	–4.5	–2.6	–2.5	–2.2	–1.7	–2.4	–8.4	–5.6	–6.5	–5.5	–3.6	–2.4	–2.5	–2.6	–2.8
Korea	0.2	0.2	1.4	1.8	2.1	–0.1	–2.7	–0.4	–1.9	–1.4	–1.0	–0.3	–0.2	0.1	0.1
Latvia	–0.2	0.3	0.8	0.3	0.2	0.5	–2.8	–4.7	–3.2	–3.1	–1.0	–1.1	–1.0	–0.3	–0.2
Lithuania	1.1	1.5	1.8	1.7	1.6	1.2	–6.5	–0.5	–0.3	–1.3	–0.8	–0.3	–0.2	–0.2	–0.2
Luxembourg	1.1	1.1	1.6	1.1	2.8	2.0	–3.7	0.4	–0.1	–3.1	–2.3	–1.7	–1.3	–1.3	–1.4
Malta	0.9	1.2	3.2	5.1	3.5	1.8	–8.2	–6.6	–4.7	–3.7	–2.3	–1.7	–1.1	–0.4	0.3
The Netherlands	–1.1	–1.0	1.0	2.2	2.2	2.4	–3.2	–2.0	0.3	–1.4	–1.2	–1.2	–1.3	–1.4	–1.4
New Zealand	0.3	1.0	1.6	2.0	1.9	–1.9	–3.7	–2.8	–2.6	–1.9	–1.4	–0.1	0.9	1.9	2.3
Norway	6.3	3.4	1.5	2.6	5.7	4.5	–4.6	8.7	23.9	10.7	9.5	8.4	7.7	7.2	6.2
Portugal	–3.0	–0.1	1.9	0.7	2.9	2.9	–3.1	–0.6	1.4	2.0	2.3	2.2	2.2	2.2	2.2
Singapore	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Slovak Republic	–1.4	–1.2	–1.2	0.2	0.1	–0.2	–4.3	–4.5	–1.2	–4.6	–3.3	–3.1	–3.0	–2.6	–2.6
Slovenia	–2.7	0.0	0.7	2.1	2.5	2.2	–6.2	–3.5	–2.2	–2.8	–1.9	–1.4	–0.9	–0.7	–0.5
Spain[1]	–3.1	–2.7	–1.9	–0.9	–0.4	–1.0	–8.1	–4.8	–2.6	–1.8	–0.7	–0.9	–0.8	–0.8	–0.8
Sweden	–1.4	0.0	1.0	1.4	0.7	0.5	–2.9	–0.2	0.9	–0.2	–0.4	0.4	0.6	0.6	0.6
Switzerland	0.0	0.8	0.4	1.3	1.4	1.4	–2.9	–0.2	1.1	0.2	0.5	0.4	0.3	0.3	0.3
United Kingdom	–3.7	–3.1	–1.8	–0.6	–0.5	–0.9	–12.0	–6.1	–2.2	–2.0	–1.9	–1.5	–1.4	–1.6	–1.8
United States[2]	–2.1	–1.7	–2.4	–2.8	–3.1	–3.5	–11.9	–9.3	–1.3	–5.5	–4.3	–4.2	–3.5	–3.0	–3.1

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: “Primary balance” is defined as the overall balance, excluding net interest payments. For country-specific details, see “Data and Conventions” in text and Table B.

[1] Data include financial sector support. For Cyprus, 2014 and 2015 balances exclude financial sector support.

[2] For cross-economy comparison, the expenditures and fiscal balances of the United States are adjusted to exclude the imputed interest on unfunded pension liabilities and the imputed compensation of employees, which are counted as expenditures under the 2008 System of National Accounts (2008 SNA) adopted by the United States, but not in economies that have not yet adopted the 2008 SNA. Data for the United States in this table may therefore differ from data published by the US Bureau of Economic Analysis.

Table A3. Advanced Economies: General Government Cyclically Adjusted Balance, 2014–28
(Percent of potential GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	–2.2	–1.9	–2.2	–2.3	–2.5	–3.2	–7.8	–7.1	–5.0	–5.6	–4.6	–4.4	–4.2	–4.1	–4.3
Euro Area	–0.9	–0.6	–0.5	–0.6	–0.3	–0.7	–4.4	–4.1	–3.7	–3.3	–2.4	–2.2	–2.1	–2.1	–2.1
G7	–2.5	–2.2	–2.7	–3.0	–3.2	–3.9	–8.9	–8.5	–5.8	–6.7	–5.6	–5.3	–5.1	–5.0	–5.2
G20 Advanced	–2.4	–2.1	–2.5	–2.7	–2.9	–3.7	–8.6	–8.1	–5.6	–6.4	–5.3	–5.1	–4.8	–4.7	–4.9
Andorra	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Australia[1]	–2.7	–2.5	–2.2	–1.5	–1.1	–4.0	–7.9	–6.3	–2.5	–1.6	–2.3	–1.9	–1.4	–1.4	–1.2
Austria	–2.2	–0.6	–1.3	–0.9	–0.3	0.2	–7.0	–4.8	–3.6	–2.1	–1.3	–1.2	–1.4	–1.5	–1.5
Belgium	–2.6	–2.3	–2.3	–0.8	–1.2	–2.8	–6.5	–5.3	–4.5	–5.2	–4.8	–4.8	–5.1	–5.5	–5.5
Canada	–0.2	0.0	–0.1	–0.3	0.1	–0.2	–9.2	–3.7	–1.1	–0.7	–0.5	–0.5	–0.5	–0.3	–0.2
Croatia	–5.1	–3.1	–0.8	0.9	0.2	2.1	–5.5	–3.3	–0.5	–1.3	–2.1	–1.3	–0.9	–0.8	–0.6
Cyprus	2.3	2.2	1.3	1.7	2.6	0.6	–3.7	–1.4	1.2	1.3	1.2	1.1	1.0	0.7	0.7
Czech Republic	–0.6	–0.4	0.7	0.8	0.1	–0.8	–5.5	–5.4	–3.8	–3.8	–2.2	–2.0	–1.9	–1.6	–1.4
Denmark	2.5	–0.5	–0.4	0.8	–0.3	3.5	2.9	3.2	2.1	0.8	0.2	0.5	0.3	0.1	0.0
Estonia	0.1	–0.2	–0.7	–1.4	–1.5	–0.6	–4.6	–2.9	–0.6	–2.5	–2.3	–2.2	–2.5	–2.6	–2.6
Finland	–0.6	0.1	–0.4	–0.9	–1.0	–1.3	–3.4	–2.4	–1.2	–1.7	–1.9	–2.3	–1.7	–1.2	–1.1
France	–2.5	–2.1	–2.0	–2.0	–1.8	–3.1	–5.9	–5.2	–4.2	–4.3	–4.1	–3.6	–3.5	–3.5	–3.7
Germany	0.8	1.2	1.1	0.8	1.5	1.3	–2.9	–3.0	–2.8	–2.4	–1.1	–0.6	–0.6	–0.5	–0.5
Greece	3.5	3.9	6.5	6.1	4.8	2.8	–2.6	–4.2	–1.8	–1.8	–1.1	–1.2	–1.2	–1.3	–1.2
Hong Kong SAR	3.6	0.7	4.7	5.5	2.3	0.3	–5.5	1.0	–4.6	–3.1	–0.4	0.5	0.8	1.4	1.3
Iceland	1.1	0.1	11.9	0.1	–1.0	–3.4	–5.6	–6.5	–4.4	–1.5	–1.5	–1.3	–0.3	–0.4	–1.0
Ireland[2]	–3.1	–1.4	–1.4	–0.9	–0.2	0.3	–4.3	–1.8	1.1	1.5	1.7	1.7	1.6	1.1	0.9
Israel	–2.5	–0.8	–1.6	–1.3	–3.9	–4.3	–9.5	–3.5	–0.2	–2.2	–2.4	–3.0	–3.4	–3.6	–3.7
Italy	–0.5	–0.3	–0.6	–1.3	–1.3	–0.7	–5.8	–6.5	–7.7	–4.8	–3.7	–3.4	–2.7	–2.8	–2.7
Japan	–6.0	–4.5	–4.5	–3.7	–3.0	–3.3	–8.1	–5.5	–6.8	–5.7	–3.8	–2.6	–2.7	–2.9	–3.3
Korea	0.7	0.7	1.8	2.3	2.6	0.5	–1.5	0.1	–1.7	–1.1	–0.8	–0.2	–0.1	0.0	0.0
Latvia	–1.1	–1.1	–0.3	–1.2	–1.5	–1.2	–2.8	–5.3	–3.6	–2.9	–1.2	–1.5	–1.8	–1.0	–0.9
Lithuania	–0.4	0.1	0.6	0.5	0.5	0.1	–6.1	–2.0	–1.3	–1.7	–1.3	–1.1	–1.1	–1.0	–1.0
Luxembourg	1.3	1.5	1.1	1.1	3.1	2.1	–2.4	–0.2	–0.5	–2.5	–1.5	–1.1	–0.8	–0.7	–0.7
Malta	–1.2	–1.6	2.1	2.6	0.7	–1.8	–5.7	–7.3	–6.5	–5.6	–3.9	–3.5	–2.9	–2.2	–1.6
The Netherlands	–0.6	–0.7	0.9	1.4	0.9	1.1	–1.2	–1.7	–1.2	–2.8	–2.5	–2.6	–2.6	–2.5	–2.5
New Zealand	0.4	0.7	1.0	1.1	0.9	–2.2	–4.3	–4.5	–4.8	–5.4	–5.5	–3.4	–1.6	–0.4	0.3
Norway[2]	–5.6	–6.6	–7.6	–7.7	–7.0	–7.5	–12.1	–9.7	–7.0	–7.4	–8.0	–8.1	–8.1	–8.2	–8.2
Portugal	–2.7	–1.1	0.2	–2.3	–0.5	–0.7	–2.7	–1.3	–1.3	–0.9	–0.3	–0.4	–0.3	–0.2	–0.2
Singapore	1.0	–0.7	0.7	1.8	0.7	1.7	–7.9	–1.1	–1.3	0.7	0.3	0.8	0.3	0.3	0.2
Slovak Republic	–2.3	–3.3	–3.1	–1.5	–1.6	–1.7	–3.9	–4.9	–1.7	–5.2	–4.3	–4.4	–4.5	–4.0	–3.9
Slovenia	–4.4	–1.9	–1.8	0.0	0.6	0.3	–6.3	–5.6	–3.9	–3.9	–2.9	–2.3	–1.9	–1.7	–1.7
Spain[2]	–1.2	–2.1	–2.5	–2.4	–2.2	–3.1	–4.5	–4.0	–4.5	–3.9	–2.9	–3.4	–3.4	–3.4	–3.4
Sweden[2]	–0.9	–0.7	0.7	1.0	0.4	–0.1	–1.5	–0.6	0.1	–0.3	–0.1	0.4	0.5	0.4	0.4
Switzerland[2]	–0.2	0.5	0.2	1.1	1.1	1.2	–2.3	–0.2	0.8	0.1	0.4	0.3	0.2	0.2	0.2
United Kingdom[2]	–2.9	–2.5	–1.6	–1.3	–1.4	–1.6	–10.7	–7.7	–6.5	–4.8	–3.4	–3.1	–3.4	–3.4	–3.5
United States[2,3]	–2.7	–2.5	–3.6	–4.3	–5.1	–6.0	–10.7	–11.3	–6.5	–8.8	–7.6	–7.6	–7.2	–7.0	–7.3

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: For country-specific details, see “Data and Conventions” in text and Table B.

[1] Data are based on the fiscal year-based potential GDP.

[2] Data for these economies include adjustments beyond the output cycle.

[3] For cross-economy comparison, the expenditures and fiscal balances of the United States are adjusted to exclude the imputed interest on unfunded pension liabilities and the imputed compensation of employees, which are counted as expenditures under the 2008 System of National Accounts (2008 SNA) adopted by the United States, but not in economies that have not yet adopted the 2008 SNA. Data for the United States in this table may therefore differ from data published by the US Bureau of Economic Analysis.

Table A4. Advanced Economies: General Government Cyclically Adjusted Primary Balance, 2014–28
(Percent of potential GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	–0.5	–0.4	–0.7	–0.8	–1.0	–1.8	–6.6	–5.7	–3.3	–3.9	–2.8	–2.4	–2.1	–1.9	–1.9
Euro Area	1.3	1.4	1.4	1.2	1.3	0.7	–3.1	–2.8	–2.1	–1.7	–0.7	–0.4	–0.2	–0.1	–0.1
G7	–0.7	–0.5	–1.0	–1.3	–1.4	–2.1	–7.4	–6.8	–3.8	–4.6	–3.3	–2.9	–2.5	–2.2	–2.3
G20 Advanced	–0.7	–0.5	–0.9	–1.1	–1.2	–2.1	–7.2	–6.5	–3.7	–4.3	–3.1	–2.7	–2.3	–2.1	–2.1
Andorra	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Australia[1]	–1.8	–1.6	–1.3	–0.7	–0.2	–3.2	–7.1	–5.5	–1.6	–0.3	–0.7	–0.3	0.2	0.3	0.5
Austria	–0.3	1.3	0.4	0.5	0.9	1.2	–6.0	–4.1	–3.0	–1.4	–0.2	0.0	0.0	–0.1	–0.1
Belgium	0.2	0.2	0.1	1.3	0.6	–1.1	–4.8	–3.9	–3.2	–3.6	–3.0	–2.8	–3.0	–3.1	–3.0
Canada	0.1	0.6	0.5	–0.1	0.2	0.0	–8.8	–4.3	–1.6	–1.0	–0.5	–0.5	–0.4	–0.2	0.0
Croatia	–2.1	0.0	2.0	3.3	2.3	4.2	–3.7	–1.8	0.8	0.3	–0.3	0.2	0.4	0.4	0.5
Cyprus	4.3	4.2	3.1	3.5	4.3	2.3	–2.2	–0.1	2.3	2.4	2.2	2.1	1.9	1.7	1.7
Czech Republic	0.4	0.5	1.5	1.5	0.7	–0.3	–4.9	–4.8	–3.2	–3.0	–1.1	–1.0	–0.8	–0.6	–0.4
Denmark	2.9	0.2	0.1	0.7	–0.6	3.2	2.6	2.8	1.9	0.4	–0.3	0.0	–0.2	–0.3	–0.5
Estonia	0.0	–0.3	–0.8	–1.5	–1.5	–0.6	–4.6	–2.9	–0.6	–2.3	–1.9	–1.8	–2.0	–2.2	–2.1
Finland	–0.5	0.3	–0.1	–0.7	–0.9	–1.2	–3.3	–2.4	–1.3	–1.7	–1.4	–1.6	–1.3	–1.0	–1.0
France	–0.5	–0.3	–0.3	–0.4	–0.2	–1.7	–4.8	–4.0	–2.5	–2.7	–2.3	–1.6	–1.3	–1.1	–0.9
Germany	2.0	2.2	2.0	1.7	2.3	1.9	–2.5	–2.6	–2.2	–1.7	–0.3	0.3	0.3	0.4	0.4
Greece	6.9	7.0	9.3	8.9	7.9	5.6	0.0	–1.9	0.6	0.9	1.6	1.7	2.0	2.1	2.2
Hong Kong SAR	3.6	0.7	3.9	4.7	0.9	–1.3	–7.3	–1.7	–7.7	–5.0	–1.8	–1.0	–0.4	0.3	0.2
Iceland	4.5	3.7	14.8	3.1	1.2	–1.3	–3.6	–4.4	–1.2	0.7	0.4	0.6	1.5	1.5	1.0
Ireland[2]	0.2	1.0	0.8	1.1	1.4	1.6	–3.3	–1.1	1.7	2.1	2.3	2.2	2.1	1.6	1.3
Israel	–0.4	0.9	0.3	0.7	–1.7	–2.4	–7.7	–0.9	3.0	0.6	0.0	–0.8	–1.1	–1.4	–1.5
Italy	3.7	3.4	3.0	2.2	2.1	2.4	–2.8	–3.2	–3.5	–1.0	0.3	0.6	1.5	1.4	1.5
Japan	–4.9	–3.4	–3.4	–2.7	–2.2	–2.6	–7.5	–4.9	–6.5	–5.5	–3.7	–2.5	–2.5	–2.6	–2.8
Korea	0.3	0.4	1.5	2.0	2.2	0.0	–2.0	–0.3	–1.9	–1.3	–0.9	–0.2	–0.1	0.1	0.1
Latvia	0.4	0.6	0.9	–0.1	–0.5	–0.3	–1.9	–4.5	–3.1	–2.4	–0.4	–0.7	–0.8	–0.3	–0.2
Lithuania	1.3	1.7	2.1	1.7	1.5	1.1	–5.3	–1.4	–1.0	–1.2	–0.7	–0.3	–0.2	–0.1	–0.2
Luxembourg	1.1	1.2	0.8	0.9	2.9	1.9	–2.6	–0.5	–0.8	–2.7	–1.8	–1.5	–1.3	–1.3	–1.4
Malta	1.4	0.7	4.1	4.4	2.2	–0.5	–4.5	–6.2	–5.5	–4.0	–2.3	–1.7	–1.1	–0.4	0.2
The Netherlands	0.5	0.2	1.8	2.2	1.7	1.7	–0.7	–1.4	–0.8	–2.2	–1.8	–1.8	–1.7	–1.5	–1.4
New Zealand	1.0	1.3	1.6	1.8	1.5	–1.6	–3.6	–3.7	–3.8	–3.8	–3.4	–1.3	0.6	2.0	2.5
Norway[2]	–8.2	–9.5	–10.4	–10.4	–9.4	–9.8	–14.4	–11.2	–8.6	–12.4	–13.6	–13.3	–13.0	–12.3	–12.3
Portugal	1.4	3.0	3.9	1.3	2.7	2.2	–0.1	0.9	0.6	1.3	2.1	2.1	2.2	2.2	2.2
Singapore	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Slovak Republic	–0.7	–1.8	–1.6	–0.3	–0.5	–0.6	–3.0	–4.0	–0.9	–4.3	–3.1	–3.1	–3.1	–2.6	–2.6
Slovenia	–1.6	0.8	0.8	2.1	2.4	1.8	–5.0	–4.5	–2.9	–3.2	–2.1	–1.4	–0.9	–0.7	–0.5
Spain[2]	1.6	0.4	–0.2	–0.2	0.0	–1.0	–2.6	–2.1	–2.3	–1.8	–0.6	–0.9	–0.8	–0.8	–0.8
Sweden[2]	–0.8	–0.6	0.7	0.9	0.3	–0.1	–1.6	–0.7	0.3	–0.1	0.1	0.7	0.6	0.6	0.6
Switzerland[2]	0.0	0.8	0.4	1.3	1.1	1.3	–2.3	0.0	0.9	0.2	0.5	0.4	0.3	0.3	0.3
United Kingdom[2]	–1.2	–1.1	–0.1	0.5	0.2	–0.3	–9.7	–5.6	–3.2	–2.3	–1.4	–0.9	–1.2	–1.6	–1.7
United States[2,3]	–0.8	–0.7	–1.6	–2.3	–2.9	–3.7	–8.6	–9.0	–4.1	–6.0	–4.6	–4.4	–3.7	–3.3	–3.4

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see "Fiscal Policy Assumptions" in text).

Note: "Cyclically adjusted primary balance" is defined as the cyclically adjusted balance plus net interest payable/paid (interest expense minus interest revenue) following the *World Economic Outlook* convention. For economy-specific details, see "Data and Conventions" in text and Table B.

[1] Data are based on the fiscal year-based potential GDP.

[2] The data for these economies include adjustments beyond the output cycle.

[3] For cross-economy comparison, expenditures and fiscal balances of the United States are adjusted to exclude the imputed interest on unfunded pension liabilities and the imputed compensation of employees, which are counted as expenditures under the 2008 System of National Accounts (2008 SNA) adopted by the United States, but not in economies that have not yet adopted the 2008 SNA. Data for the United States in this table may therefore differ from data published by the US Bureau of Economic Analysis.

Table A5. Advanced Economies: General Government Revenue, 2014–28

(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	36.5	36.2	36.0	35.9	36.0	35.7	36.1	36.9	37.3	35.7	36.0	36.2	36.5	36.6	36.6
Euro Area	46.8	46.4	46.3	46.2	46.4	46.3	46.4	47.2	47.0	46.6	46.2	46.2	46.0	45.9	45.8
G7	36.5	36.3	36.0	35.8	35.8	35.6	36.1	36.9	37.3	35.3	35.8	36.1	36.5	36.7	36.7
G20 Advanced	35.7	35.6	35.4	35.2	35.3	35.1	35.6	36.4	36.8	35.0	35.4	35.7	36.0	36.2	36.2
Andorra	33.8	35.0	38.6	38.2	38.6	38.2	41.3	37.9	40.0	39.2	39.7	39.8	39.8	39.9	39.9
Australia	33.8	34.5	34.8	35.0	35.6	34.5	35.8	35.6	35.7	36.6	36.2	35.3	35.0	34.9	34.9
Austria	49.6	50.0	48.5	48.5	48.9	49.2	48.8	50.3	49.6	49.3	49.1	48.9	48.7	48.7	48.7
Belgium	52.5	51.3	50.8	51.3	51.4	49.9	49.9	49.9	49.7	50.4	51.0	51.2	51.1	51.0	51.2
Canada	38.5	40.0	40.3	40.3	41.0	40.6	41.8	41.5	40.6	40.7	40.6	40.6	40.7	40.9	40.9
Croatia	43.7	43.9	44.8	45.0	45.4	46.5	46.8	46.2	45.5	45.6	44.7	45.0	45.3	44.0	43.9
Cyprus	40.1	39.5	37.5	38.3	39.0	39.4	38.8	41.5	41.9	40.5	40.3	40.0	39.4	39.2	39.1
Czech Republic	40.5	41.3	40.5	40.5	41.5	41.3	41.5	41.4	41.0	42.1	41.4	40.8	40.7	40.8	41.0
Denmark	56.4	53.2	52.4	52.3	51.3	53.8	53.9	53.9	48.3	49.4	49.2	49.1	49.1	49.3	49.3
Estonia	38.0	39.1	38.4	38.2	38.1	39.2	39.5	39.4	38.7	38.5	39.3	40.1	40.4	40.5	40.6
Finland	54.3	54.1	53.9	53.0	52.5	52.4	51.6	53.0	52.2	51.9	52.2	52.5	52.5	52.4	52.4
France	53.3	53.2	53.0	53.5	53.4	52.3	52.4	52.6	53.5	51.9	51.6	51.6	51.4	51.4	51.3
Germany	44.9	45.1	45.5	45.5	46.3	46.5	46.1	47.3	47.0	46.4	46.2	46.4	46.6	46.7	46.7
Greece	46.5	48.2	50.2	49.4	49.3	48.0	49.6	50.0	50.2	47.3	46.4	46.4	45.9	44.4	43.5
Hong Kong SAR	20.8	18.6	22.6	22.9	20.7	20.4	20.7	23.7	21.6	20.9	22.7	23.4	23.6	23.9	23.9
Iceland	46.1	43.1	59.0	45.4	44.8	42.0	42.3	41.4	43.5	44.1	43.6	43.2	42.7	42.3	41.7
Ireland	33.9	27.0	27.4	25.8	25.4	24.8	22.2	22.8	22.8	23.0	23.1	23.1	22.9	22.5	22.3
Israel	36.0	36.4	36.2	37.2	35.6	34.8	34.1	36.5	37.2	34.8	34.5	34.1	34.1	34.2	34.3
Italy	47.9	47.8	46.7	46.3	46.2	47.0	47.3	48.3	48.8	48.8	47.7	47.6	47.2	46.9	46.6
Japan	32.8	33.6	33.6	33.6	34.3	34.2	35.5	36.6	37.2	36.7	36.6	36.6	36.6	36.6	36.6
Korea	20.4	20.3	21.1	21.8	22.9	22.9	22.9	25.7	27.1	24.1	24.0	24.5	24.5	24.5	24.5
Latvia	36.1	35.9	35.7	35.7	37.3	37.2	37.5	37.4	36.5	36.4	37.5	36.6	36.5	36.4	36.4
Lithuania	33.4	34.2	33.6	32.9	33.7	34.0	34.7	36.3	35.8	37.8	36.3	35.8	35.2	35.2	35.0
Luxembourg	41.9	41.7	41.9	42.6	45.3	45.3	43.5	43.6	43.8	43.3	43.9	44.2	44.6	45.0	45.3
Malta	38.2	37.2	37.5	37.7	38.0	36.2	35.7	35.4	34.4	35.3	35.2	35.1	35.1	35.1	35.1
The Netherlands	43.8	42.9	43.8	43.8	43.8	43.9	44.1	43.7	43.3	43.2	42.8	42.8	42.9	42.9	43.0
New Zealand	37.3	37.6	37.4	37.0	37.4	36.3	37.8	38.6	39.1	38.5	39.2	40.0	40.1	40.2	39.5
Norway	53.8	54.2	54.4	54.2	55.5	56.7	54.2	57.5	63.9	55.3	54.9	54.5	54.3	53.8	53.4
Portugal	44.4	43.8	42.9	42.4	42.9	42.5	43.4	44.9	44.4	44.5	44.6	44.6	44.5	44.1	44.0
Singapore	17.2	17.3	18.6	18.9	17.6	17.8	17.5	17.4	17.3	17.7	18.2	19.0	19.7	19.9	19.9
Slovak Republic	40.2	42.9	40.0	38.5	38.7	39.3	39.4	40.1	40.3	42.6	39.1	38.5	38.3	38.2	38.2
Slovenia	45.3	45.9	44.2	44.0	44.2	44.1	43.7	44.9	43.9	43.7	43.3	43.3	43.5	43.6	43.8
Spain	39.2	38.7	38.2	38.2	39.2	39.2	41.8	43.2	42.4	43.1	42.9	42.4	41.2	41.2	41.2
Sweden	48.1	48.4	49.8	49.6	49.6	48.7	48.3	48.1	48.1	47.7	47.6	48.7	48.5	48.5	48.5
Switzerland	31.9	33.0	32.7	33.6	33.0	33.3	34.0	34.2	32.5	32.0	31.7	31.5	31.5	31.5	31.5
United Kingdom	35.7	35.7	36.2	36.6	36.6	36.3	36.9	38.0	38.8	39.8	39.5	39.4	39.5	39.6	39.8
United States	31.4	31.7	31.2	30.6	30.2	30.2	30.8	31.4	32.5	29.3	30.3	30.7	31.4	31.8	31.8

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).
Note: For economy-specific details, see “Data and Conventions” in text and Table B.

Table A6. Advanced Economies: General Government Expenditure, 2014–28

(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	39.6	38.7	38.7	38.3	38.4	38.7	46.4	44.4	40.5	40.8	40.4	40.4	40.4	40.4	40.5
Euro Area	49.3	48.4	47.7	47.1	46.9	46.9	53.5	52.4	50.6	50.1	48.9	48.5	48.1	47.9	47.9
G7	40.1	39.3	39.3	39.1	39.2	39.4	47.7	46.0	41.4	41.8	41.4	41.4	41.5	41.5	41.7
G20 Advanced	39.2	38.5	38.5	38.3	38.3	38.7	46.8	45.0	40.8	41.1	40.7	40.7	40.7	40.7	40.9
Andorra	31.7	33.3	34.6	34.9	35.9	35.8	42.3	39.0	35.1	35.9	36.3	36.4	36.4	36.2	36.3
Australia	36.8	37.3	37.3	36.8	36.9	38.9	44.5	42.1	38.1	38.0	38.5	37.3	36.6	36.4	36.1
Austria	52.3	51.0	50.1	49.3	48.8	48.7	56.8	56.1	52.8	51.7	51.1	50.6	50.4	50.3	50.2
Belgium	55.6	53.7	53.1	52.0	52.3	51.9	58.9	55.4	53.5	55.3	55.8	56.0	56.2	56.5	56.7
Canada	38.4	40.0	40.8	40.5	40.7	40.6	52.7	45.9	41.4	41.4	41.3	41.2	41.2	41.2	41.1
Croatia	48.9	47.4	45.8	44.2	45.3	44.3	54.1	48.7	45.1	46.4	46.5	46.0	46.1	44.8	44.5
Cyprus	40.3	39.5	37.3	36.4	42.6	38.1	44.6	43.5	39.8	38.6	38.7	38.5	38.2	38.2	38.2
Czech Republic	42.6	41.9	39.8	39.0	40.6	41.1	47.2	46.5	44.7	46.2	43.7	42.8	42.6	42.5	42.5
Denmark	55.2	54.5	52.5	50.5	50.5	49.7	53.5	49.8	44.9	47.5	48.3	48.7	48.9	49.2	49.3
Estonia	37.8	39.5	39.4	39.2	39.3	39.1	44.9	41.8	39.6	42.3	42.5	42.9	43.1	43.1	43.1
Finland	57.3	56.5	55.6	53.6	53.4	53.3	57.2	55.8	53.0	54.5	54.8	55.3	54.5	53.7	53.5
France	57.2	56.8	56.7	56.5	55.6	55.4	61.3	59.1	58.3	56.8	56.1	55.6	55.0	54.9	54.9
Germany	44.3	44.1	44.4	44.2	44.3	45.0	50.5	50.9	49.5	49.3	47.9	47.3	47.2	47.2	47.2
Greece	50.7	51.2	49.9	48.5	48.5	48.1	60.1	57.7	52.5	48.9	47.1	47.3	46.8	45.5	44.7
Hong Kong SAR	17.3	18.0	18.3	17.4	18.4	21.0	29.9	23.7	28.2	24.8	23.7	23.2	23.0	22.6	22.6
Iceland	45.8	43.5	46.4	44.4	43.8	43.6	51.3	49.9	47.5	44.9	44.8	44.5	43.0	42.6	42.6
Ireland	37.5	29.0	28.1	26.1	25.3	24.3	27.2	24.4	21.2	21.3	21.2	21.3	21.3	21.4	21.4
Israel	38.3	37.5	37.9	38.4	39.2	38.7	44.9	40.1	36.6	36.4	36.5	36.9	37.3	37.7	37.9
Italy	50.9	50.3	49.1	48.8	48.4	48.5	57.0	57.3	56.7	53.8	51.7	50.9	49.9	49.6	49.1
Japan	38.4	37.3	37.2	36.7	36.7	37.3	44.5	42.7	44.1	42.4	40.3	39.1	39.3	39.5	39.9
Korea	19.8	19.7	19.5	19.6	20.4	22.6	25.1	25.7	28.7	25.3	24.8	24.8	24.7	24.5	24.5
Latvia	37.8	37.4	36.1	36.5	38.1	37.6	41.2	42.8	40.3	40.1	39.3	38.5	38.5	37.5	37.3
Lithuania	34.0	34.4	33.3	32.4	33.2	33.8	41.9	37.3	36.4	39.6	37.7	36.9	36.2	36.1	36.0
Luxembourg	40.6	40.4	40.0	41.3	42.3	43.1	47.0	42.9	43.6	46.2	45.8	45.5	45.3	45.6	46.0
Malta	39.9	38.2	36.4	34.5	36.0	35.7	45.2	43.1	40.1	40.6	39.1	38.5	37.9	37.3	36.6
The Netherlands	46.1	44.8	43.6	42.5	42.3	42.1	47.8	46.1	43.5	45.2	44.7	44.8	45.1	45.3	45.5
New Zealand	37.7	37.3	36.5	35.6	36.1	38.8	42.1	42.1	42.6	41.9	42.8	42.2	41.4	40.6	39.5
Norway	45.2	48.2	50.4	49.2	47.7	50.2	56.7	47.5	38.5	40.2	40.5	41.5	42.2	42.9	43.6
Portugal	51.7	48.1	44.8	45.4	43.2	42.4	49.2	47.7	44.8	44.7	44.7	44.9	44.7	44.3	44.2
Singapore	12.6	14.4	15.3	13.6	13.9	14.0	24.3	16.2	16.5	14.5	15.4	15.6	16.8	17.1	17.3
Slovak Republic	43.3	45.6	42.5	39.5	39.7	40.5	44.8	45.6	42.3	48.1	43.5	42.9	42.8	42.2	42.2
Slovenia	50.8	48.7	46.2	44.1	43.5	43.4	51.4	49.5	47.0	47.2	46.0	45.5	45.4	45.3	45.5
Spain	45.3	44.0	42.5	41.3	41.8	42.3	51.9	50.0	47.1	47.1	45.9	45.8	44.6	44.6	44.6
Sweden	49.7	48.4	48.8	48.2	48.8	48.1	51.0	48.2	47.3	48.1	48.3	48.5	48.1	48.1	48.1
Switzerland	32.2	32.5	32.4	32.4	31.7	32.0	37.0	34.5	31.5	31.9	31.3	31.2	31.3	31.3	31.3
United Kingdom	41.2	40.3	39.5	39.0	38.7	38.5	49.9	46.3	44.3	44.2	43.4	43.1	43.2	43.2	43.3
United States[1]	35.4	35.2	35.6	35.4	35.6	36.0	44.8	43.0	36.3	37.5	37.7	38.2	38.4	38.5	38.8

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: For economy-specific details, see “Data and Conventions” in text and Table B.

[1] For cross-economy comparison, expenditures and fiscal balances of the United States are adjusted to exclude the imputed interest on unfunded pension liabilities and the imputed compensation of employees, which are counted as expenditures under the 2008 System of National Accounts (2008 SNA) adopted by the United States, but not in economies that have not yet adopted the 2008 SNA. Data for the United States in this table may therefore differ from data published by the US Bureau of Economic Analysis.

Table A7. Advanced Economies: General Government Gross Debt, 2014–28
(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average[1]	103.7	103.3	105.8	103.4	102.9	104.1	122.9	117.0	112.3	112.1	112.7	113.8	114.6	115.3	116.3
Euro Area	92.8	90.9	90.1	87.7	85.7	83.7	96.8	94.8	91.0	89.6	88.3	87.1	86.1	85.5	84.9
G7	117.4	116.4	119.6	117.5	117.3	118.3	140.4	133.9	128.0	127.8	128.9	130.5	131.7	132.8	134.3
G20 Advanced	111.3	110.9	114.0	111.8	111.6	113.1	134.1	127.9	122.6	122.7	124.0	125.5	126.6	127.6	129.0
Andorra	42.0	41.0	39.8	37.9	36.3	35.4	46.4	48.6	39.4	37.7	35.7	34.4	33.4	32.3	31.1
Australia[2]	34.0	37.8	40.6	41.2	41.8	46.7	57.2	55.9	50.7	51.9	55.6	56.3	56.3	55.7	54.9
Austria	83.8	84.4	82.5	78.6	74.1	70.6	82.9	82.3	78.5	74.8	74.0	71.7	70.7	68.9	68.2
Belgium	107.0	105.2	105.0	102.0	99.9	97.6	112.0	109.1	105.1	106.0	106.8	108.5	110.9	113.5	115.9
Canada[2]	85.5	92.0	92.4	90.9	90.8	90.2	118.9	115.1	107.4	106.4	103.3	100.6	98.6	96.6	94.7
Croatia	83.8	83.2	79.7	76.5	73.2	71.0	86.9	78.3	68.8	63.8	61.8	60.3	58.5	56.9	55.2
Cyprus	108.8	106.8	102.6	92.6	98.1	90.4	113.5	101.0	86.5	78.6	70.9	66.8	61.7	58.4	55.1
Czech Republic	41.9	39.7	36.6	34.2	32.1	30.0	37.7	42.0	44.2	45.4	44.4	44.1	43.8	43.4	42.9
Denmark	44.3	39.8	37.2	35.9	34.0	33.7	42.3	36.0	29.7	30.1	29.0	28.7	28.6	28.6	28.6
Estonia	10.6	10.1	10.0	9.1	8.2	8.5	18.6	17.8	18.5	21.6	24.0	25.9	27.5	29.1	30.5
Finland	64.5	68.3	68.0	66.0	64.8	64.9	74.7	72.5	72.5	73.6	76.5	79.0	80.2	80.4	80.3
France	94.9	95.6	98.0	98.1	97.8	97.4	114.7	113.0	111.8	110.0	110.5	110.4	110.4	110.5	110.8
Germany	75.3	71.9	69.0	65.2	61.9	59.5	68.7	69.0	66.1	65.9	64.0	61.8	59.9	58.6	57.5
Greece	181.8	179.1	183.7	183.2	190.7	185.5	212.4	200.7	178.1	168.0	160.2	155.7	151.4	148.2	145.3
Hong Kong SAR[2]	0.1	0.1	0.1	0.1	0.1	0.3	1.0	1.9	4.3	6.1	7.0	7.6	8.7	9.6	9.7
Iceland	115.3	97.3	82.5	71.7	63.2	66.5	77.7	75.4	68.9	61.2	54.6	51.6	47.9	44.4	41.8
Ireland	104.0	76.5	74.4	67.4	62.9	57.1	58.1	54.4	44.4	42.7	39.0	35.7	33.2	31.1	29.5
Israel	64.9	63.2	61.8	59.8	60.1	59.2	70.9	67.8	60.7	58.2	56.8	56.4	56.3	56.5	56.9
Italy	135.4	135.3	134.8	134.2	134.4	134.1	154.9	149.9	144.4	143.7	143.2	142.8	141.9	141.0	140.1
Japan	233.3	228.3	232.4	231.3	232.4	236.4	258.6	255.1	260.1	255.2	251.9	250.6	251.1	251.9	252.8
Korea	39.7	40.8	41.2	40.1	40.0	42.1	48.7	51.3	53.8	54.3	55.6	56.5	57.1	57.5	57.9
Latvia	41.6	37.1	40.4	39.0	37.0	36.5	42.0	43.7	40.8	40.6	39.5	38.7	38.3	37.2	36.0
Lithuania	40.5	42.7	39.9	39.3	33.7	35.8	46.3	43.7	38.1	36.1	34.4	33.0	31.8	30.9	30.1
Luxembourg	21.9	21.1	19.6	21.8	20.9	22.4	24.6	24.5	24.8	27.6	29.3	30.2	30.4	30.5	30.4
Malta	62.1	56.2	54.7	47.8	43.4	40.0	52.2	54.0	52.3	54.1	55.2	56.1	56.3	55.3	54.3
The Netherlands	67.9	64.6	61.9	57.0	52.4	48.5	54.7	51.6	50.1	49.5	48.6	48.7	49.0	49.6	50.3
New Zealand	34.2	34.2	33.4	31.1	28.1	31.8	43.3	47.4	46.4	46.1	49.9	52.3	52.0	49.7	47.7
Norway	29.7	34.3	37.9	38.3	39.4	40.6	46.1	42.8	37.1	37.4	36.3	36.2	35.9	35.2	34.5
Portugal	132.9	131.2	131.5	126.1	121.5	116.6	134.9	125.4	113.9	108.3	104.0	99.9	96.2	92.9	89.7
Singapore	97.7	102.2	106.5	107.8	109.4	127.8	149.0	147.7	167.5	167.9	168.3	168.8	169.3	169.8	170.2
Slovak Republic	53.5	51.7	52.3	51.5	49.4	48.0	58.9	61.0	57.8	56.7	56.5	57.5	60.3	61.7	63.0
Slovenia	80.3	82.6	78.5	74.2	70.3	65.4	79.6	74.4	72.6	68.5	66.5	64.7	63.4	62.4	61.3
Spain	105.1	103.3	102.7	101.8	100.4	98.2	120.3	116.8	111.6	107.3	104.7	103.9	103.8	103.8	103.8
Sweden	44.9	43.7	42.3	40.7	39.2	35.5	39.8	36.4	32.7	32.3	32.6	32.2	31.5	30.7	29.7
Switzerland	42.1	42.2	40.9	41.8	39.8	39.6	43.2	41.1	40.9	39.5	37.7	36.4	35.0	33.9	32.6
United Kingdom	86.1	86.7	86.6	85.6	85.2	84.5	104.6	105.2	101.9	104.1	105.9	107.3	108.5	108.2	108.2
United States[2]	104.5	105.1	107.2	106.2	107.4	108.7	133.5	126.4	121.3	123.3	126.9	130.3	132.9	135.1	137.5

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: For economy-specific details, see “Data and Conventions” in text and Table B.

[1] The average does not include the debt incurred by the European Union and used to finance the grants portion of the NextGenerationEU package. This totaled €58 billion (0.4 percent of EU GDP) as of December 31, 2021, and €158 billion (1 percent of EU GDP) as of February 16, 2023. Debt incurred by the European Union and used to on-lend to member states is included within member state debt data and regional aggregates.

[2] For cross-economy comparison, gross debt levels reported by national statistical agencies for economies that have adopted the 2008 System of National Accounts (Australia, Canada, Hong Kong SAR, and the United States) are adjusted to exclude unfunded pension liabilities of government employees’ defined-benefit pension plans.

Table A8. Advanced Economies: General Government Net Debt, 2014–28

(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average[1]	74.9	74.9	76.5	74.1	73.9	74.8	86.8	84.5	82.4	82.6	83.9	84.9	85.7	86.5	87.6
Euro Area	76.3	75.1	74.6	72.5	70.8	69.2	79.1	77.7	75.3	74.6	73.9	73.2	72.7	72.4	72.2
G7	86.4	85.8	87.7	85.4	85.5	86.2	99.9	97.9	95.4	95.8	97.6	99.0	100.2	101.4	102.9
G20 Advanced	80.9	80.7	82.6	80.2	80.4	81.5	94.6	92.7	90.5	91.1	93.0	94.3	95.5	96.6	98.0
Andorra	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Australia[2]	19.1	22.1	23.4	23.3	24.1	27.9	36.1	35.8	29.9	29.3	32.8	34.3	34.6	34.4	33.8
Austria	59.1	58.3	56.9	55.9	50.7	48.0	59.3	60.2	58.4	56.2	56.2	54.6	54.3	53.1	52.9
Belgium[3]	93.4	92.0	91.2	88.3	86.4	84.7	97.5	94.4	91.4	92.9	94.2	96.4	99.1	102.1	104.8
Canada[2]	21.7	18.5	18.0	12.5	11.6	8.5	15.7	15.4	14.2	14.6	14.6	14.5	14.4	14.2	13.8
Croatia	68.9	70.0	67.7	64.5	61.3	58.0	69.9	63.2	53.5	49.8	48.8	47.9	46.7	45.7	44.6
Cyprus	90.3	90.6	85.3	76.9	51.1	46.1	56.5	53.9	46.7	. . .	. . .	. . .	. . .	. . .	. . .
Czech Republic	29.4	28.1	25.0	21.5	19.6	18.1	23.6	26.4	29.9	31.2	30.0	29.4	29.1	28.7	27.9
Denmark	18.1	16.2	17.5	15.8	13.4	12.3	14.8	9.4	5.1	3.1	2.1	1.6	1.3	1.1	1.1
Estonia	–3.8	–2.0	–1.9	–1.8	–1.8	–2.2	3.0	4.5	4.0	8.0	11.1	13.7	16.0	18.1	20.1
Finland[4]	17.2	18.4	21.2	21.8	24.5	27.0	33.2	34.3	32.9	34.1	35.6	37.3	38.0	38.0	37.7
France	85.5	86.3	89.2	89.4	89.2	88.9	101.2	100.4	101.4	99.6	100.1	100.0	100.0	100.1	100.4
Germany	54.9	52.2	49.3	45.5	42.8	40.7	46.1	47.2	45.8	46.5	45.7	44.4	43.2	42.4	41.7
Greece	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Hong Kong SAR[2]	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Iceland[5]	88.2	78.1	67.7	60.3	50.7	54.4	61.0	60.2	57.3	50.5	44.6	42.1	38.9	35.9	33.8
Ireland[6]	85.6	65.6	65.5	58.6	54.1	48.9	49.6	44.4	36.6	35.5	32.2	29.3	27.1	25.4	24.0
Israel	61.6	59.9	58.4	56.6	57.1	56.8	66.6	64.2	58.6	56.1	54.7	54.3	54.3	54.5	54.8
Italy	121.4	122.2	121.6	121.3	121.8	121.7	141.5	137.4	132.7	132.6	132.5	132.4	131.9	131.3	130.6
Japan	144.9	144.5	149.5	148.1	151.1	151.7	162.3	156.7	161.5	158.5	155.8	154.0	153.5	153.2	153.2
Korea	7.5	9.5	9.7	9.6	9.6	11.7	18.3	20.8	23.4	23.8	25.1	26.0	26.7	27.1	27.5
Latvia	30.3	31.4	31.2	30.5	28.6	28.1	32.4	33.2	31.8	32.3	31.8	31.6	31.5	30.8	30.0
Lithuania	32.5	35.4	32.9	32.9	27.7	30.3	40.9	38.9	34.1	32.4	31.0	29.7	28.7	28.0	27.3
Luxembourg	–10.9	–12.2	–11.6	–11.3	–11.8	–14.1	–10.5	–10.9	–8.1	–3.6	–0.3	2.0	3.4	4.6	5.6
Malta	52.7	47.8	41.8	35.4	32.6	29.0	41.8	44.0	47.0	49.2	50.6	51.7	52.1	51.4	50.5
The Netherlands	55.1	53.3	51.5	46.6	42.9	39.8	44.8	42.2	41.0	40.6	39.8	39.9	40.2	40.6	41.2
New Zealand	7.9	7.3	6.6	5.6	4.7	6.9	10.4	13.8	19.2	24.5	30.0	33.0	33.2	31.3	29.7
Norway	–74.1	–85.1	–83.7	–78.6	–70.9	–74.2	–79.0	–85.3	–65.5	–90.8	–99.0	–109.1	–118.4	–127.0	–135.0
Portugal	120.6	121.0	119.4	116.0	113.4	109.9	123.0	118.1	108.1	102.9	98.8	94.9	91.4	88.2	85.2
Singapore	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Slovak Republic	49.5	47.3	46.9	45.8	43.4	43.1	48.9	49.6	48.2	48.8	49.6	51.3	54.0	55.7	57.2
Slovenia	63.8	63.6	62.7	60.2	53.4	49.9	57.2	56.3	55.0	52.9	52.3	51.9	51.8	51.9	51.9
Spain	86.2	86.0	87.1	86.2	84.9	83.7	102.9	100.9	97.2	93.9	92.1	91.8	92.1	92.5	92.8
Sweden	11.2	11.1	8.9	6.2	6.1	4.9	8.4	7.3	6.1	7.1	8.5	9.3	9.6	9.7	9.5
Switzerland	20.8	21.0	21.6	20.8	18.7	17.3	20.4	20.6	20.4	19.0	17.3	15.9	14.6	13.4	12.1
United Kingdom	77.9	78.2	77.6	76.2	75.4	74.6	93.6	94.1	98.9	99.0	99.6	97.2	96.7	96.5	96.5
United States[2]	81.1	80.9	81.8	80.4	81.1	83.1	98.3	98.3	95.1	96.7	100.7	104.0	106.6	109.0	111.6

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see "Fiscal Policy Assumptions" in text).

Note: For economy-specific details, see "Data and Conventions" in text, and Table B.

[1] The average does not include the debt incurred by the European Union and used to finance the grants portion of the NextGenerationEU package. This totaled €58 billion (0.4 percent of EU GDP) as of December 31, 2021, and €158 billion (1 percent of EU GDP) as of February 16, 2023. Debt incurred by the European Union and used to on-lend to member states is included within member state debt data and regional aggregates.

[2] For cross-economy comparison, net debt levels reported by national statistical agencies for economies that have adopted the 2008 System of National Accounts (Australia, Canada, Hong Kong SAR, and the United States) are adjusted to exclude unfunded pension liabilities of government employees' defined-benefit pension plans.

[3] Belgium's net debt series has been revised to ensure consistency between liabilities and assets. "Net debt" is defined as gross debt (Maastricht definition) minus assets in the form of currency and deposits, loans, and debt securities.

[4] Net debt figures were revised to include only categories of assets corresponding to the liabilities covered by the Maastricht definition of "gross debt."

[5] "Net debt" for Iceland is defined as gross debt minus currency and deposits.

[6] "Net debt" for Ireland is defined as gross general debt minus debt instrument assets, namely, currency and deposits, debt securities, and loans. Net debt was previously defined as general government debt less currency and deposits.

Table A9. Emerging Market and Middle-Income Economies: General Government Overall Balance, 2014–28

(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	–2.3	–4.1	–4.4	–3.9	–3.5	–4.5	–8.8	–5.2	–5.1	–5.6	–5.5	–5.3	–5.2	–5.2	–5.3
Asia	–1.7	–3.1	–3.7	–3.7	–4.2	–5.8	–9.7	–6.5	–7.3	–6.9	–6.8	–6.8	–6.9	–7.0	–7.1
Europe	–1.5	–2.7	–2.8	–1.8	0.3	–0.6	–5.5	–1.9	–2.5	–4.8	–3.8	–3.0	–2.6	–2.4	–2.2
Latin America	–4.6	–5.8	–5.2	–5.4	–5.0	–3.8	–8.3	–3.9	–3.4	–4.6	–4.6	–3.3	–2.9	–2.7	–2.6
MENA	–1.7	–7.9	–8.9	–5.1	–1.7	–2.5	–8.5	–2.2	3.1	–0.4	–1.3	–1.5	–1.5	–1.5	–1.8
G20 Emerging	–2.4	–4.2	–4.5	–4.1	–4.1	–5.1	–9.3	–5.4	–6.0	–6.3	–6.1	–5.9	–5.9	–5.9	–6.0
Algeria	–8.0	–15.7	–13.4	–8.6	–6.8	–9.6	–11.9	–7.2	–2.9	–8.6	–12.0	–10.6	–9.7	–8.9	–8.5
Angola	–5.7	–2.9	–4.5	–6.6	2.3	0.8	–1.9	3.8	0.7	–1.9	1.0	1.4	1.2	1.8	1.2
Argentina	–4.3	–6.0	–6.7	–6.7	–5.4	–4.4	–8.6	–4.3	–3.8	–4.0	–3.7	–1.9	–0.5	–0.1	0.1
Belarus	0.1	–3.0	–1.7	–0.3	1.8	0.9	–2.9	–1.7	–3.9	–0.7	0.6	1.6	1.7	1.7	1.7
Brazil	–5.7	–8.8	–7.6	–8.5	–7.0	–5.0	–11.9	–2.5	–3.1	–7.1	–6.0	–5.3	–4.8	–4.4	–4.4
Bulgaria	–3.7	–2.8	1.5	0.8	0.1	–1.0	–2.9	–2.8	–0.8	–2.8	–3.2	–3.6	–2.8	–2.8	–2.7
Chile	–1.5	–2.1	–2.7	–2.6	–1.5	–2.7	–7.1	–7.5	1.4	–1.6	–1.3	–0.7	–0.3	0.2	0.2
China[1]	–0.7	–2.5	–3.4	–3.4	–4.3	–6.1	–9.7	–6.0	–7.5	–7.1	–7.0	–7.3	–7.5	–7.6	–7.8
Colombia	–1.7	–3.5	–2.3	–2.5	–4.7	–3.5	–7.0	–7.1	–6.2	–3.5	–2.4	–2.6	–2.4	–2.2	–1.9
Dominican Republic	–2.8	0.0	–3.1	–3.1	–2.2	–3.5	–7.9	–2.9	–3.2	–3.2	–3.1	–2.9	–2.6	–2.3	–2.1
Ecuador[2]	–8.1	–6.7	–10.1	–5.8	–2.8	–3.5	–7.1	–1.6	0.0	–1.0	–0.8	–0.6	–0.4	–0.3	–0.3
Egypt	–10.7	–10.4	–11.8	–9.9	–9.0	–7.6	–7.5	–7.0	–5.8	–4.6	–10.7	–11.1	–10.1	–8.8	–7.8
Hungary	–2.8	–2.0	–1.8	–2.5	–2.1	–2.0	–7.5	–7.1	–6.2	–5.5	–3.8	–2.8	–2.1	–2.0	–1.5
India	–7.1	–7.2	–7.1	–6.2	–6.4	–7.7	–12.9	–9.6	–9.2	–8.8	–8.5	–8.0	–7.7	–7.4	–7.2
Indonesia	–2.1	–2.6	–2.5	–2.5	–1.8	–2.2	–6.1	–4.5	–2.3	–2.2	–2.2	–2.1	–2.1	–2.1	–2.0
Iran	–1.0	–1.5	–1.8	–1.6	–1.6	–4.5	–5.8	–4.2	–4.1	–5.5	–5.7	–6.0	–6.3	–6.6	–6.9
Kazakhstan	2.5	–6.3	–4.5	–4.3	2.6	–0.6	–7.0	–5.0	0.1	–0.9	–1.1	–0.9	–1.3	–1.5	–1.8
Kuwait	21.5	4.5	0.8	1.8	6.5	2.2	–11.7	–0.3	19.1	14.0	9.5	8.2	6.2	3.7	1.9
Lebanon	–6.2	–7.5	–8.9	–8.7	–11.3	–10.4	–3.5	0.6	–4.9	. . .	. . .	. . .	. . .	. . .	. . .
Malaysia[3]	–2.6	–2.5	–2.6	–2.4	–2.6	–2.0	–4.9	–5.8	–5.9	–4.7	–4.4	–4.3	–4.3	–4.3	–4.2
Mexico	–4.4	–3.9	–2.7	–1.0	–2.1	–2.3	–4.3	–3.8	–4.3	–3.9	–5.4	–2.6	–2.7	–2.7	–2.7
Morocco	–4.8	–4.5	–4.4	–3.2	–3.4	–3.6	–7.1	–6.0	–5.2	–4.9	–4.2	–3.8	–3.5	–3.3	–3.0
Oman	–1.6	–13.5	–19.6	–10.5	–6.7	–4.8	–15.7	–3.1	7.4	6.2	5.9	4.1	3.7	3.3	1.9
Pakistan	–4.4	–4.7	–3.9	–5.2	–5.7	–7.8	–7.0	–6.0	–7.8	–8.1	–7.6	–6.9	–5.4	–4.8	–4.4
Peru	–0.2	–2.1	–2.2	–2.9	–2.0	–1.4	–9.0	–2.5	–1.4	–2.2	–1.8	–1.2	–0.5	–0.2	–0.2
Philippines	1.3	0.1	–0.7	–0.8	–1.5	–1.5	–5.5	–6.2	–5.5	–4.8	–4.3	–3.9	–3.4	–2.7	–2.3
Poland	–3.7	–2.6	–2.4	–1.5	–0.2	–0.7	–6.9	–1.8	–3.7	–5.3	–4.7	–4.6	–4.8	–4.5	–4.0
Qatar	15.4	21.7	–4.9	–2.6	5.9	4.8	1.3	4.3	13.5	10.8	10.1	9.2	9.0	9.0	8.8
Romania	–2.0	–1.3	–2.5	–2.9	–2.7	–4.6	–9.6	–6.7	–5.8	–6.3	–6.0	–5.9	–5.7	–5.6	–5.5
Russian Federation	–1.1	–3.4	–3.7	–1.5	2.9	1.9	–4.0	0.8	–1.4	–3.7	–2.6	–1.3	–0.6	–0.1	0.3
Saudi Arabia	–3.5	–15.5	–13.7	–8.9	–5.5	–4.2	–10.7	–2.3	2.5	–0.3	0.3	0.5	0.7	1.0	0.6
South Africa	–3.9	–4.4	–3.7	–4.0	–3.7	–4.7	–9.6	–5.5	–4.7	–6.4	–6.5	–6.8	–6.5	–6.5	–6.7
Sri Lanka	–6.0	–6.6	–5.0	–5.1	–5.0	–7.5	–12.2	–11.7	–10.2	. . .	. . .	. . .	. . .	. . .	. . .
Thailand	–0.8	0.1	0.6	–0.4	0.1	–0.8	–4.5	–7.0	–4.6	–2.9	–2.7	–2.8	–2.7	–2.5	–2.4
Türkiye	–1.4	–1.3	–2.3	–2.2	–3.8	–4.7	–5.1	–4.0	–1.7	–5.4	–3.7	–3.3	–3.4	–3.4	–3.4
Ukraine	–4.5	–1.2	–2.5	–2.4	–2.1	–2.1	–5.9	–4.0	–15.7	–19.1	–17.8	–9.6	–5.3	–3.8	–2.0
United Arab Emirates	1.8	–6.6	–3.1	–0.2	3.8	2.6	–2.5	4.0	9.9	5.1	4.4	3.9	3.7	3.4	3.1
Uruguay[4]	–2.6	–1.9	–2.7	–2.5	–1.9	–2.6	–4.7	–2.6	–2.5	–3.2	–2.6	–2.5	–2.2	–2.0	–1.8
Venezuela	–9.8	–8.1	–8.5	–13.3	–30.3	–10.0	–5.0	–4.6	–6.0	. . .	. . .	. . .	. . .	. . .	. . .

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: For country-specific details, see “Data and Conventions” in text and Table C. MENA = Middle East and North Africa.

[1] China's deficit and public debt numbers presented in this table cover a narrower perimeter of the general government than IMF staff's estimates in China Article IV reports (see IMF 2023 for a reconciliation of the two estimates).

[2] The data for Ecuador reflect net lending/borrowing of the nonfinancial public sector.

[3] The general government overall balance in 2019 includes a one-off refund of tax arrears in 2019 of 2.4 percent of GDP.

[4] Data are for the nonfinancial public sector, which includes central government, local government, social security funds, nonfinancial public corporations, and Banco de Seguros del Estado. The coverage of fiscal data was changed from the consolidated public sector to the nonfinancial public sector with the October 2019 submission. With this narrower coverage, the central bank balances are not included in the fiscal data. Historical data were also revised accordingly. Starting in October 2018, the public pension system has been receiving transfers in the context of a new law that compensates persons affected by the creation of the mixed pension system. These funds are recorded as revenues, consistent with the IMF's methodology. Therefore, data and projections for 2018–22 are affected by these transfers, which amounted to 1.2 percent of GDP in 2018, 1.1 percent of GDP in 2019, 0.6 percent of GDP in 2020, and 0.3 percent of GDP in 2021 and are projected to be 0.1 percent of GDP in 2022 and 0 thereafter. See IMF Country Report No. 19/64 for further details. The disclaimer about the public pension system applies only to the revenues and net lending/borrowing series.

Table A10. Emerging Market and Middle-Income Economies: General Government Primary Balance, 2014–28

(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	–0.7	–2.4	–2.8	–2.1	–1.7	–2.7	–7.0	–3.4	–3.2	–3.4	–3.1	–2.8	–2.7	–2.6	–2.7
Asia	–0.5	–1.9	–2.4	–2.2	–2.8	–4.3	–8.0	–4.9	–5.7	–5.0	–4.7	–4.6	–4.6	–4.5	–4.5
Europe	–0.4	–1.5	–1.7	–0.8	1.4	0.4	–4.5	–0.9	–1.5	–3.3	–2.2	–1.3	–1.0	–0.8	–0.5
Latin America	–1.4	–1.6	–1.7	–1.5	–1.1	–0.3	–5.1	–0.6	0.5	–0.4	–0.3	0.7	0.9	1.1	1.1
MENA	–1.2	–7.5	–8.6	–4.8	–0.8	–1.3	–7.6	–1.0	3.9	0.7	0.3	0.4	0.4	0.5	0.3
G20 Emerging	–0.8	–2.4	–2.8	–2.2	–2.2	–3.3	–7.5	–3.7	–4.1	–4.1	–3.7	–3.4	–3.3	–3.3	–3.3
Algeria	–7.8	–15.4	–13.1	–7.7	–6.3	–9.0	–11.0	–6.5	–1.4	–7.3	–10.1	–8.3	–7.2	–6.1	–5.6
Angola	–4.7	–1.1	–1.7	–3.0	7.0	6.4	5.0	9.0	4.7	3.4	5.8	6.4	6.3	6.0	6.0
Argentina	–3.5	–4.4	–4.8	–4.2	–2.2	–0.4	–6.2	–2.5	–1.8	–1.6	–0.5	0.4	1.4	2.0	2.0
Belarus	1.1	–1.3	0.3	1.6	3.8	2.6	–1.2	–0.2	–3.0	1.0	2.3	3.3	3.4	3.2	3.2
Brazil	–0.3	–0.4	–1.6	–2.2	–1.0	–0.3	–7.9	2.0	2.1	–1.2	–0.2	0.2	0.7	1.1	1.1
Bulgaria	–3.4	–2.4	1.8	1.2	0.3	–0.8	–2.8	–2.8	–0.8	–2.8	–3.0	–3.1	–2.4	–2.3	–2.3
Chile	–1.4	–1.9	–2.4	–2.3	–1.1	–2.4	–6.6	–6.9	0.9	–2.0	–1.2	–0.5	0.0	0.5	0.5
China	–0.1	–2.0	–2.7	–2.6	–3.5	–5.2	–8.8	–5.1	–6.6	–6.0	–5.8	–5.8	–5.8	–5.8	–5.9
Colombia	–0.2	–1.7	–0.4	–0.5	–2.5	–1.0	–4.4	–4.4	–2.4	0.3	1.7	0.8	0.5	0.6	0.8
Dominican Republic	–0.4	2.3	–0.6	–0.5	0.4	–0.7	–4.7	0.2	–0.4	–0.1	0.2	0.5	0.8	1.1	1.2
Ecuador[1]	–7.9	–6.3	–9.5	–4.7	–1.4	–1.9	–5.6	–1.4	0.5	–0.2	0.2	0.7	0.8	0.9	1.0
Egypt	–4.0	–3.9	–4.1	–2.4	–0.4	1.3	1.2	1.1	0.4	2.3	1.5	2.0	2.0	2.2	2.3
Hungary	1.0	1.3	1.2	0.1	0.2	0.1	–5.3	–5.1	–3.9	–2.8	–0.7	–0.3	0.1	0.0	–0.1
India	–2.6	–2.7	–2.5	–1.5	–1.7	–3.0	–7.3	–4.4	–4.1	–3.4	–2.9	–2.5	–2.3	–2.2	–2.2
Indonesia	–0.9	–1.2	–1.0	–0.9	–0.1	–0.4	–4.1	–2.5	–0.4	–0.2	–0.1	0.0	0.0	0.1	0.1
Iran	–1.0	–1.4	–1.3	–1.0	–0.8	–3.5	–4.6	–3.2	–3.1	–3.0	–2.9	–2.8	–2.7	–2.5	–2.4
Kazakhstan	2.0	–5.9	–4.3	–5.2	1.8	–0.8	–7.7	–4.4	0.8	0.2	0.0	0.2	–0.1	–0.3	–0.5
Kuwait[2]	12.6	–7.5	–14.2	–9.9	–4.3	–8.6	–28.3	–14.3	7.2	0.6	–3.4	–4.5	–6.3	–8.9	–10.6
Lebanon	2.5	1.4	0.4	0.8	–1.4	–0.3	–0.5	1.9	–4.3	. . .	. . .	. . .	. . .	. . .	. . .
Malaysia	–0.9	–0.9	–0.8	–0.6	–0.8	0.0	–3.1	–3.7	–3.8	–2.3	–1.8	–1.6	–1.5	–1.5	–1.3
Mexico	–1.7	–1.2	0.3	2.5	1.5	1.4	–0.5	0.0	0.7	1.6	–0.7	1.8	1.6	1.5	1.4
Morocco	–2.2	–2.0	–2.0	–0.9	–1.2	–1.4	–4.6	–3.9	–3.1	–2.4	–1.5	–1.0	–0.6	–0.3	–0.2
Oman	–1.9	–14.1	–20.0	–11.1	–5.2	–4.6	–13.0	–0.9	8.0	6.8	6.6	4.8	4.3	3.8	3.3
Pakistan	–0.3	–0.5	–0.1	–1.4	–1.8	–3.0	–1.5	–1.1	–3.0	–1.2	0.4	0.5	0.5	0.4	0.4
Peru	0.7	–1.2	–1.3	–1.9	–0.9	–0.2	–6.9	–1.2	0.0	–0.7	–0.2	0.2	0.7	0.9	0.8
Philippines	3.5	2.1	1.0	0.9	0.2	0.1	–3.7	–4.4	–3.5	–2.6	–1.8	–1.4	–1.0	–0.4	–0.1
Poland	–1.7	–0.8	–0.7	0.1	1.2	0.6	–5.6	–0.7	–2.2	–3.5	–2.9	–2.6	–2.7	–2.4	–1.9
Qatar	16.6	23.1	–3.4	–1.2	7.3	6.6	3.6	6.1	14.9	12.1	11.3	10.3	10.1	10.1	9.8
Romania	–0.5	–0.1	–1.3	–1.8	–1.4	–3.4	–8.3	–5.3	–3.8	–3.9	–3.8	–4.0	–3.7	–3.7	–3.4
Russian Federation	–0.7	–3.1	–3.2	–1.0	3.4	2.2	–3.7	1.1	–1.1	–3.4	–2.3	–1.0	–0.3	0.1	0.4
Saudi Arabia	–4.2	–17.5	–16.5	–11.3	–6.0	–4.2	–12.5	–2.0	2.5	0.2	0.7	1.0	1.2	1.4	1.0
South Africa	–1.2	–1.4	–0.6	–0.8	–0.4	–1.1	–5.5	–1.3	–0.2	–1.2	–0.8	–0.6	0.3	0.7	0.8
Sri Lanka	–1.9	–2.1	–0.2	0.0	0.6	–1.9	–5.9	–5.7	–3.7	. . .	. . .	. . .	. . .	. . .	. . .
Thailand	–0.1	0.7	1.0	0.1	0.7	–0.2	–3.9	–6.1	–3.5	–1.7	–1.5	–1.6	–1.5	–1.3	–1.2
Türkiye	0.5	0.6	–1.0	–0.9	–2.3	–2.9	–3.2	–2.3	–0.4	–3.1	–0.8	–0.3	–0.4	–0.4	–0.4
Ukraine	–1.2	3.0	1.6	1.4	1.2	1.0	–3.0	–1.1	–12.6	–14.7	–12.3	–5.3	–1.1	0.0	1.4
United Arab Emirates	2.1	–6.3	–2.9	0.0	4.0	2.9	–2.2	4.3	10.4	5.7	5.0	4.5	4.3	4.0	3.6
Uruguay[3]	–0.5	0.2	–0.3	–0.2	0.5	–0.5	–2.1	–0.6	–0.5	–1.7	–1.1	–0.8	–0.4	–0.2	0.0
Venezuela	–7.5	–6.8	–7.7	–13.1	–30.3	–10.0	–4.9	–4.6	–5.8	. . .	. . .	. . .	. . .	. . .	. . .

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: “Primary balance” is defined as the overall balance, excluding net interest payments. For country-specific details, see “Data and Conventions” in text and Table C. MENA = Middle East and North Africa.

[1] The data for Ecuador reflect primary balance of the nonfinancial public sector.

[2] Interest revenue is proxied by IMF staff estimates of investment income. The country team does not have the breakdown of investment income between interest revenue and dividends.

[3] Data are for the nonfinancial public sector, which includes central government, local government, social security funds, nonfinancial public corporations, and Banco de Seguros del Estado. The coverage of fiscal data was changed from the consolidated public sector to the nonfinancial public sector with the October 2019 submission. With this narrower coverage, the central bank balances are not included in the fiscal data. Historical data were also revised accordingly. Starting in October 2018, the public pension system has been receiving transfers in the context of a new law that compensates persons affected by the creation of the mixed pension system. These funds are recorded as revenues, consistent with the IMF's methodology. Therefore, data and projections for 2018–22 are affected by these transfers, which amounted to 1.2 percent of GDP in 2018, 1.1 percent of GDP in 2019, 0.6 percent of GDP in 2020, and 0.3 percent of GDP in 2021 and are projected to be 0.1 percent of GDP in 2022 and 0 thereafter. See IMF Country Report No. 19/64 for further details. The disclaimer about the public pension system applies only to the revenues and net lending/borrowing series.

Table A11. Emerging Market and Middle-Income Economies: General Government Cyclically Adjusted Balance, 2014–28

(Percent of potential GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	–2.6	–3.5	–3.8	–3.7	–3.7	–4.6	–7.3	–5.1	–5.6	–6.0	–5.9	–5.7	–5.7	–5.7	–5.7
Asia	–1.7	–2.8	–3.6	–3.5	–4.2	–5.5	–8.1	–5.9	–6.6	–6.5	–6.5	–6.7	–6.9	–7.0	–7.0
Europe	–1.1	–2.2	–2.2	–1.6	–0.2	–0.9	–4.7	–2.1	–2.9	–5.2	–4.1	–3.3	–2.8	–2.6	–2.3
Latin America	–5.1	–5.7	–4.7	–5.1	–4.3	–3.3	–6.3	–3.7	–3.6	–4.9	–4.7	–3.3	–3.0	–2.8	–2.7
MENA	–9.6	–10.7	–10.3	–8.2	–7.4	–7.8	–8.0	–7.2	–4.2	–5.4	–7.3	–7.7	–7.2	–6.5	–5.9
G20 Emerging	–2.5	–3.6	–3.9	–3.8	–3.9	–4.9	–7.8	–5.1	–5.8	–6.3	–6.2	–6.0	–6.1	–6.1	–6.2
Algeria	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Angola	–9.6	–1.4	–2.9	–4.7	3.2	2.0	1.3	4.4	1.4	–0.4	1.2	1.0	1.1	1.9	1.3
Argentina	–3.4	–6.2	–6.0	–7.2	–5.0	–3.4	–5.0	–3.3	–3.8	–2.3	–2.3	–1.0	0.0	0.3	0.2
Belarus	–0.8	–2.3	0.0	0.4	1.5	0.3	–3.0	–2.6	–3.4	–0.2	0.6	1.3	1.3	1.2	1.0
Brazil	–7.5	–8.6	–6.0	–7.2	–6.2	–4.4	–10.2	–2.2	–3.2	–7.7	–6.2	–5.4	–4.9	–4.5	–4.4
Bulgaria	–3.0	–2.7	1.4	0.6	–0.2	–1.9	–1.4	–2.9	–1.1	–2.7	–3.1	–3.5	–2.8	–2.7	–2.7
Chile[1]	–0.5	0.5	–1.0	–2.0	–1.5	–1.7	–1.6	–11.9	–1.9	–3.4	–2.3	–1.8	–1.2	–0.9	–0.7
China	–0.7	–2.2	–3.1	–3.2	–4.1	–5.8	–8.4	–5.6	–6.6	–6.6	–6.7	–7.0	–7.4	–7.6	–7.8
Colombia	–2.4	–3.9	–2.6	–2.3	–4.2	–2.5	–4.9	–7.4	–7.7	–4.0	–2.5	–3.1	–3.1	–2.8	–2.6
Dominican Republic	–4.3	–4.2	–3.8	–3.7	–3.3	–3.2	–7.6	–3.4	–3.5	–4.0	–3.9	–3.5	–3.4	–2.9	–2.6
Ecuador[2]	–8.9	–8.0	–10.1	–5.2	–3.4	–3.4	–4.9	–1.3	–0.8	–0.8	–1.0	–0.4	–0.2	–0.2	0.0
Egypt	–11.0	–10.8	–11.4	–10.1	–9.0	–7.3	–6.6	–7.1	–6.0	–4.6	–10.1	–10.7	–10.0	–8.8	–7.8
Hungary	–1.3	–1.1	–0.6	–1.8	–2.3	–2.9	–6.7	–7.1	–6.2	–4.9	–3.5	–2.6	–2.1	–2.0	–1.5
India	–6.6	–7.0	–7.4	–6.2	–6.8	–7.6	–9.1	–8.7	–9.3	–8.8	–8.5	–8.0	–7.7	–7.4	–7.2
Indonesia	–2.3	–2.7	–2.5	–2.4	–1.8	–2.1	–5.3	–3.9	–2.1	–2.2	–2.2	–2.1	–2.1	–2.1	–2.0
Iran	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Kazakhstan	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Kuwait	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Lebanon	–13.5	–11.6	–11.5	–13.7	–12.7	–18.4	–12.1	–2.4	0.2	. . .	. . .	. . .	. . .	. . .	. . .
Malaysia	–2.6	–2.6	–2.7	–2.6	–3.6	–1.6	–3.9	–5.0	–6.2	–4.9	–4.5	–4.5	–4.5	–4.4	–4.2
Mexico	–4.4	–4.2	–4.0	–2.7	–2.7	–2.8	–3.6	–3.3	–4.3	–4.2	–5.7	–2.7	–2.7	–2.7	–2.7
Morocco	–6.1	–4.8	–4.9	–4.3	–3.9	–3.8	–5.5	–6.0	–5.1	–5.0	–4.4	–3.8	–3.5	–3.3	–3.0
Oman	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Pakistan	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Peru	–0.1	–1.5	–1.9	–2.2	–1.9	–0.9	–6.0	–3.9	–2.0	–2.1	–1.9	–1.6	–1.2	–1.1	–1.1
Philippines	1.2	0.2	–0.8	–0.8	–1.5	–1.5	–3.3	–5.3	–5.6	–4.8	–4.3	–4.0	–3.5	–2.8	–2.4
Poland	–2.9	–2.2	–1.7	–1.6	–1.5	–2.4	–5.4	–2.1	–5.0	–5.0	–4.2	–4.4	–4.8	–4.5	–4.0
Qatar	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Romania	–1.0	–0.4	–1.4	–3.1	–3.8	–5.7	–8.2	–6.8	–6.2	–6.1	–5.8	–5.8	–5.6	–5.6	–5.4
Russian Federation	–0.1	–3.1	–3.2	–1.0	2.9	2.0	–4.4	0.5	–1.1	–3.8	–2.7	–1.5	–0.8	–0.3	0.1
Saudi Arabia	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
South Africa	–4.0	–4.2	–3.6	–3.8	–3.7	–4.4	–5.9	–5.1	–5.7	–6.2	–6.3	–6.3	–6.4	–6.5	–6.7
Sri Lanka	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Thailand	–0.7	0.4	0.8	–0.4	–0.1	–1.0	–3.6	–5.8	–4.0	–2.4	–2.2	–2.7	–2.6	–2.4	–1.2
Türkiye	–1.6	–1.6	–2.1	–2.9	–4.2	–4.0	–3.6	–4.4	–2.3	–6.3	–4.3	–3.8	–3.6	–3.5	–3.4
Ukraine	–3.2	1.5	–0.9	–1.4	–2.2	–1.7	–4.4	–3.3	–15.0	. . .	. . .	. . .	. . .	. . .	. . .
United Arab Emirates	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Uruguay[3]	–3.5	–2.1	–2.7	–2.7	–1.9	–2.0	–3.0	–1.5	–2.1	–2.8	–2.4	–2.2	–2.0	–1.9	–1.7
Venezuela	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: For country-specific details, see “Data and Conventions” in text and Table C. MENA = Middle East and North Africa.

[1] Data for these economies include adjustments beyond the output cycle.

[2] The data for Ecuador reflect cyclically adjusted balance of the nonfinancial public sector.

[3] Data are for the nonfinancial public sector, which includes central government, local government, social security funds, nonfinancial public corporations, and Banco de Seguros del Estado. The coverage of fiscal data was changed from the consolidated public sector to the nonfinancial public sector with the October 2019 submission. With this narrower coverage, the central bank balances are not included in the fiscal data. Historical data were also revised accordingly. Starting in October 2018, the public pension system has been receiving transfers in the context of a new law that compensates persons affected by the creation of the mixed pension system. These funds are recorded as revenues, consistent with the IMF's methodology. Therefore, data and projections for 2018–22 are affected by these transfers, which amounted to 1.2 percent of GDP in 2018, 1.1 percent of GDP in 2019, 0.6 percent of GDP in 2020, and 0.3 percent of GDP in 2021 and are projected to be 0.1 percent of GDP in 2022 and 0 thereafter. See IMF Country Report No. 19/64 for further details. The disclaimer about the public pension system applies only to the revenues and net lending/borrowing series.

Table A12. Emerging Market and Middle-Income Economies: General Government Cyclically Adjusted Primary Balance, 2014–28

(Percent of potential GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	–0.8	–1.6	–1.9	–1.7	–1.8	–2.7	–5.5	–3.3	–3.6	–3.7	–3.3	–3.1	–3.0	–3.0	–2.9
Asia	–0.4	–1.7	–2.2	–2.0	–2.8	–4.1	–6.5	–4.4	–5.0	–4.6	–4.5	–4.5	–4.6	–4.5	–4.5
Europe	0.1	–0.9	–1.1	–0.5	1.0	0.2	–3.7	–1.0	–2.0	–3.8	–2.4	–1.5	–1.1	–0.9	–0.6
Latin America	–1.8	–1.4	–1.2	–1.1	–0.3	0.2	–3.2	–0.5	0.3	–0.4	–0.3	0.7	0.9	1.1	1.1
MENA	–5.2	–6.2	–5.1	–3.5	–2.2	–2.3	–2.6	–2.2	0.2	–0.8	–0.5	0.0	0.3	0.6	0.9
G20 Emerging	–0.7	–1.7	–2.1	–1.8	–2.0	–3.1	–6.0	–3.3	–3.8	–4.0	–3.7	–3.5	–3.5	–3.4	–3.5
Algeria	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Angola	–8.4	0.2	–0.3	–1.5	7.6	7.1	6.9	9.4	5.2	4.5	5.9	6.2	6.2	6.1	6.1
Argentina	–2.7	–4.6	–4.1	–4.7	–1.8	0.5	–2.8	–1.5	–1.8	–0.1	0.8	1.3	1.9	2.3	2.2
Belarus	0.2	–0.6	1.9	2.4	3.5	2.1	–1.4	–1.1	–2.4	1.5	2.3	3.1	3.0	2.7	2.5
Brazil	–1.8	–0.2	–0.2	–1.1	–0.2	0.3	–6.3	2.2	2.1	–1.7	–0.4	0.2	0.7	1.1	1.1
Bulgaria	–2.8	–2.3	1.7	0.9	0.0	–1.8	–1.3	–2.9	–1.1	–2.6	–2.9	–3.1	–2.4	–2.3	–2.3
Chile[1]	–0.4	0.7	–0.7	–1.7	–1.2	–1.4	–1.1	–11.2	–2.4	–3.7	–2.1	–1.5	–0.9	–0.6	–0.5
China	–0.2	–1.7	–2.5	–2.5	–3.3	–4.9	–7.5	–4.7	–5.7	–5.4	–5.4	–5.6	–5.7	–5.8	–5.9
Colombia	–0.8	–2.1	–0.6	–0.3	–2.0	0.1	–2.4	–4.4	–3.3	0.5	2.4	1.1	0.6	0.8	1.1
Dominican Republic	–2.0	–1.9	–1.3	–1.2	–0.7	–0.5	–4.6	–0.3	–0.7	–0.9	–0.6	–0.2	0.0	0.5	0.8
Ecuador[2]	–8.7	–7.6	–9.5	–4.1	–2.0	–1.9	–3.4	–1.1	–0.3	0.1	0.1	0.8	1.0	1.1	1.3
Egypt	–4.3	–4.4	–3.7	–2.6	–0.5	1.5	2.0	0.9	0.2	2.3	2.1	2.5	2.1	2.2	2.3
Hungary	2.3	2.2	2.3	0.8	0.0	–0.7	–4.5	–5.0	–3.9	–2.3	–0.4	–0.2	0.1	0.0	–0.1
India	–2.2	–2.5	–2.8	–1.4	–2.0	–2.9	–3.9	–3.7	–4.2	–3.4	–2.9	–2.5	–2.3	–2.2	–2.2
Indonesia	–1.1	–1.3	–1.0	–0.8	0.0	–0.4	–3.3	–2.0	–0.2	–0.1	–0.1	0.0	0.0	0.1	0.2
Iran	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Kazakhstan	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Kuwait	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Lebanon	–4.9	–2.8	–2.1	–3.9	–2.1	–7.4	–9.4	–1.3	0.7	. . .	. . .	. . .	. . .	. . .	. . .
Malaysia	–0.8	–1.0	–0.9	–0.8	–1.7	0.4	–2.3	–2.9	–4.1	–2.5	–2.0	–1.8	–1.7	–1.5	–1.3
Mexico	–1.7	–1.4	–0.9	0.9	1.1	1.0	0.0	0.3	0.7	1.4	–0.9	1.7	1.6	1.5	1.4
Morocco	–3.5	–2.3	–2.5	–1.9	–1.6	–1.7	–3.1	–3.9	–3.1	–2.5	–1.6	–1.0	–0.6	–0.3	–0.2
Oman	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Pakistan	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Peru	0.8	–0.6	–1.0	–1.2	–0.7	0.3	–4.0	–2.6	–0.7	–0.7	–0.3	–0.2	0.0	0.0	0.0
Philippines	3.3	2.2	1.0	0.8	0.1	0.1	–1.7	–3.5	–3.6	–2.6	–1.8	–1.4	–1.0	–0.4	–0.1
Poland	–0.9	–0.5	0.0	–0.1	–0.1	–1.0	–4.1	–1.0	–3.4	–3.3	–2.4	–2.4	–2.6	–2.4	–1.9
Qatar	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Romania	0.4	0.8	–0.2	–2.0	–2.4	–4.5	–6.9	–5.3	–4.1	–3.8	–3.7	–3.9	–3.7	–3.7	–3.4
Russian Federation	0.3	–2.8	–2.8	–0.5	3.4	2.3	–4.1	0.8	–0.8	–3.5	–2.5	–1.2	–0.5	–0.1	0.2
Saudi Arabia	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
South Africa	–1.2	–1.2	–0.5	–0.6	–0.3	–0.9	–2.1	–1.0	–1.2	–1.0	–0.7	–0.2	0.4	0.7	0.8
Sri Lanka	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Thailand	0.0	0.9	1.2	0.2	0.5	–0.3	–3.0	–4.9	–3.0	–1.3	–1.1	–1.5	–1.4	–1.2	0.0
Türkiye	0.4	0.2	–0.8	–1.6	–2.6	–2.2	–1.8	–2.7	–1.0	–4.0	–1.4	–0.8	–0.6	–0.4	–0.4
Ukraine	0.0	5.4	3.0	2.3	1.1	1.3	–1.6	–0.5	–11.8	. . .	. . .	. . .	. . .	. . .	. . .
United Arab Emirates	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Uruguay[3]	–1.4	0.1	–0.3	–0.3	0.5	0.1	–0.5	0.4	–0.1	–1.3	–0.9	–0.6	–0.2	–0.1	0.1
Venezuela	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see "Fiscal Policy Assumptions" in text).

Note: "Cyclically adjusted primary balance" is defined as the cyclically adjusted balance plus net interest payable/paid (interest expense minus interest revenue) following the *World Economic Outlook* convention. For country-specific details, see "Data and Conventions" in text and Table C. MENA = Middle East and North Africa.

[1] Data for these economies include adjustments beyond the output cycle. For country-specific details, see "Data and Conventions" in text and Table C.

[2] The data for Ecuador reflect cyclically adjusted primary balance of the nonfinancial public sector.

[3] Data are for the nonfinancial public sector, which includes central government, local government, social security funds, nonfinancial public corporations, and Banco de Seguros del Estado. The coverage of fiscal data was changed from the consolidated public sector to the nonfinancial public sector with the October 2019 submission. With this narrower coverage, the central bank balances are not included in the fiscal data. Historical data were also revised accordingly. Starting in October 2018, the public pension system has been receiving transfers in the context of a new law that compensates persons affected by the creation of the mixed pension system. These funds are recorded as revenues, consistent with the IMF's methodology. Therefore, data and projections for 2018–22 are affected by these transfers, which amounted to 1.2 percent of GDP in 2018, 1.1 percent of GDP in 2019, 0.6 percent of GDP in 2020, and 0.3 percent of GDP in 2021 and are projected to be 0.1 percent of GDP in 2022 and 0 thereafter. See IMF Country Report No. 19/64 for further details. The disclaimer about the public pension system applies only to the revenues and net lending/borrowing series.

Table A13. Emerging Market and Middle-Income Economies: General Government Revenue, 2014–28
(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	28.7	27.8	27.4	27.7	28.1	27.7	25.7	26.7	26.9	26.8	27.0	26.9	27.0	26.9	26.9
Asia	25.6	26.3	26.1	26.2	26.3	25.5	23.6	24.7	24.0	24.3	24.4	24.5	24.7	24.8	24.8
Europe	34.3	33.3	33.6	33.6	35.0	35.1	34.3	34.3	33.9	33.6	33.9	34.0	34.2	34.0	34.0
Latin America	30.7	30.6	30.8	30.5	30.3	30.7	28.6	29.9	31.4	30.4	30.7	30.7	30.8	30.8	30.7
MENA	32.5	26.3	23.9	25.5	29.3	29.5	26.7	28.1	31.0	29.7	29.1	28.5	28.1	27.7	27.1
G20 Emerging	28.8	28.4	28.3	28.4	28.5	27.9	25.8	26.8	26.7	26.7	26.9	26.9	27.0	27.1	27.1
Algeria	33.3	30.5	28.6	32.6	33.5	32.2	30.5	29.9	34.2	33.7	29.8	29.1	28.4	27.9	27.7
Angola	30.7	24.1	17.5	17.5	22.9	21.2	21.3	23.3	23.2	22.2	21.6	20.9	20.4	19.8	19.6
Argentina	34.6	35.4	34.9	34.4	33.5	33.3	33.5	33.5	33.4	33.8	34.6	34.7	35.3	35.5	35.5
Belarus	38.9	38.8	39.0	38.7	39.6	38.3	35.2	35.3	32.2	34.9	35.9	37.0	37.2	37.1	37.1
Brazil	38.5	40.3	41.0	39.8	40.5	41.8	38.0	40.9	43.3	41.1	42.1	42.2	42.6	42.7	42.5
Bulgaria	33.4	34.5	34.2	32.8	34.4	34.9	34.9	35.8	37.4	34.5	35.9	34.5	34.7	34.4	34.1
Chile	22.4	22.9	22.7	22.9	24.1	23.7	22.0	26.0	28.1	25.3	25.6	25.9	26.0	26.0	26.0
China	28.2	29.0	28.9	29.2	29.0	28.1	25.7	26.6	25.9	26.5	26.7	26.9	27.1	27.3	27.5
Colombia	29.5	27.8	27.7	26.8	30.0	29.4	26.6	27.2	27.9	31.1	32.4	31.8	31.1	30.7	30.4
Dominican Republic	14.2	16.6	13.9	14.0	14.2	14.4	14.2	15.6	15.3	15.7	15.0	15.0	15.0	15.0	15.0
Ecuador[1]	38.3	36.5	33.1	34.8	38.1	36.1	31.7	36.2	39.4	36.9	36.4	35.7	35.2	34.5	33.9
Egypt	23.2	20.9	19.2	20.7	19.7	19.3	18.2	18.6	18.9	18.1	18.1	18.3	18.8	19.0	19.3
Hungary	47.3	48.4	45.0	44.3	44.0	44.0	43.6	41.2	41.6	42.8	44.0	44.0	43.9	43.5	43.5
India	19.1	19.9	20.1	20.0	20.0	19.2	18.2	19.9	19.4	19.4	19.4	19.5	19.6	19.7	19.8
Indonesia	16.5	14.9	14.3	14.1	14.9	14.2	12.5	13.6	15.2	15.1	14.9	14.9	14.9	14.9	14.9
Iran	13.1	14.8	15.3	15.5	13.6	9.7	7.2	8.0	8.2	8.3	8.4	8.5	8.6	8.8	8.9
Kazakhstan	23.7	16.6	17.0	19.8	21.4	19.7	17.5	17.1	21.8	22.0	20.9	20.6	20.3	20.1	19.9
Kuwait	65.8	58.9	54.9	53.8	58.3	55.2	54.8	54.4	60.9	65.6	59.7	57.6	56.0	53.8	52.2
Lebanon	22.6	19.2	19.4	21.9	21.0	20.8	16.0	9.8	6.3	. . .	. . .	. . .	. . .	. . .	. . .
Malaysia	23.3	22.2	20.3	19.6	20.2	21.6	20.2	18.6	19.5	17.9	17.2	16.9	16.8	16.6	16.5
Mexico	22.6	22.7	23.8	24.0	22.8	23.0	23.5	23.0	24.2	23.8	23.7	23.7	23.5	23.5	23.3
Morocco	25.9	23.9	24.1	24.6	24.2	23.8	27.0	25.3	27.0	27.8	27.4	27.2	27.2	27.2	27.1
Oman	39.8	31.1	25.0	29.0	31.6	33.9	28.9	33.0	37.1	32.4	31.5	29.5	28.4	27.5	25.7
Pakistan	13.7	13.1	13.8	14.0	13.4	11.3	13.3	12.4	12.1	11.4	12.5	12.4	12.4	12.3	12.3
Peru	22.3	20.2	18.7	18.2	19.3	19.8	17.8	21.0	22.1	20.4	20.6	20.6	20.6	20.6	20.6
Philippines	18.2	17.9	18.3	18.7	19.4	20.2	20.4	21.0	20.4	20.0	20.8	21.0	21.5	21.8	22.1
Poland	39.2	39.1	38.9	39.9	41.2	41.1	41.3	42.3	39.8	41.8	42.3	42.3	42.2	42.0	42.1
Qatar	47.7	60.2	35.2	32.1	34.8	37.3	36.0	33.7	37.8	34.6	34.0	32.8	32.5	32.2	32.0
Romania	31.8	32.8	29.3	28.2	29.0	28.8	28.6	30.5	31.0	30.7	30.8	30.7	31.0	30.9	30.9
Russian Federation	33.9	31.9	32.9	33.4	35.5	35.7	35.2	35.6	34.6	32.4	33.2	33.7	34.1	33.8	33.8
Saudi Arabia	36.2	24.4	20.8	23.2	28.5	29.5	28.4	29.6	30.7	29.2	29.5	29.5	29.5	29.6	28.7
South Africa	25.4	25.8	26.2	25.8	26.4	26.7	25.0	27.1	27.7	26.8	26.5	26.9	27.1	27.1	27.1
Sri Lanka	11.2	12.6	13.2	12.8	12.6	11.9	8.8	8.3	8.3	. . .	. . .	. . .	. . .	. . .	. . .
Thailand	21.4	22.3	21.9	21.1	21.4	21.0	20.4	20.2	20.1	20.0	20.1	20.0	20.0	20.0	20.1
Türkiye	31.6	31.9	32.5	31.2	30.8	30.9	28.9	27.2	26.4	29.1	29.7	29.9	29.9	29.8	29.9
Ukraine	40.3	41.9	38.3	39.3	39.8	39.4	39.7	36.5	50.3	43.9	41.5	40.6	41.0	41.4	41.8
United Arab Emirates	34.0	20.7	29.7	28.0	30.5	31.0	28.7	30.4	32.8	31.9	31.1	30.6	30.3	30.0	29.6
Uruguay[2]	26.5	26.5	27.0	27.2	28.5	27.9	28.1	27.3	27.2	26.5	27.1	27.1	27.1	27.1	27.0
Venezuela	21.8	14.9	11.2	8.5	6.4	8.7	4.3	5.9	6.0	. . .	. . .	. . .	. . .	. . .	. . .

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: For country-specific details, see “Data and Conventions” in text and Table C. MENA = Middle East and North Africa.

[1] The data for Ecuador reflect revenue of the nonfinancial public sector.

[2] Data are for the nonfinancial public sector, which includes central government, local government, social security funds, nonfinancial public corporations, and Banco de Seguros del Estado. The coverage of fiscal data was changed from the consolidated public sector to the nonfinancial public sector with the October 2019 submission. With this narrower coverage, the central bank balances are not included in the fiscal data. Historical data were also revised accordingly. Starting in October 2018, the public pension system has been receiving transfers in the context of a new law that compensates persons affected by the creation of the mixed pension system. These funds are recorded as revenues, consistent with the IMF's methodology. Therefore, data and projections for 2018–22 are affected by these transfers, which amounted to 1.2 percent of GDP in 2018, 1.1 percent of GDP in 2019, 0.6 percent of GDP in 2020, and 0.3 percent of GDP in 2021 and are projected to be 0.1 percent of GDP in 2022 and 0 thereafter. See IMF Country Report No. 19/64 for further details. The disclaimer about the public pension system applies only to the revenues and net lending/borrowing series.

Table A14. Emerging Market and Middle-Income Economies: General Government Expenditure, 2014–28
(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	31.0	31.9	31.9	31.6	31.7	32.2	34.5	31.9	32.0	32.5	32.5	32.2	32.2	32.2	32.2
Asia	27.3	29.4	29.8	29.9	30.5	31.2	33.3	31.1	31.4	31.2	31.2	31.4	31.6	31.7	31.9
Europe	35.8	35.9	36.5	35.4	34.7	35.6	39.7	36.2	36.4	38.3	37.7	37.0	36.8	36.5	36.2
Latin America	35.3	36.4	36.0	35.9	35.3	34.5	36.9	33.8	34.8	35.0	35.3	34.0	33.7	33.5	33.3
MENA	34.2	34.2	32.8	30.6	30.9	32.1	35.2	30.3	27.9	30.0	30.4	30.0	29.7	29.2	28.9
G20 Emerging	31.2	32.6	32.8	32.5	32.6	33.1	35.1	32.2	32.7	33.0	33.0	32.8	32.9	33.0	33.1
Algeria	41.3	46.2	42.0	41.1	40.3	41.8	42.4	37.1	37.0	42.3	41.8	39.6	38.0	36.8	36.3
Angola	36.5	27.1	22.0	24.1	20.6	20.4	23.3	19.5	22.5	24.1	20.7	19.5	19.2	18.1	18.4
Argentina	38.9	41.4	41.5	41.1	38.9	37.7	42.1	37.8	37.3	37.7	38.3	36.6	35.8	35.6	35.5
Belarus	38.8	41.8	40.7	39.0	37.8	37.4	38.0	37.1	36.1	35.5	35.3	35.4	35.5	35.3	35.4
Brazil	44.2	49.1	48.6	48.3	47.5	46.8	49.9	43.5	46.4	48.2	48.1	47.5	47.4	47.1	46.8
Bulgaria	37.1	37.3	32.7	32.0	34.3	35.9	37.8	38.6	38.2	37.3	39.1	38.1	37.6	37.2	36.8
Chile	23.9	25.0	25.4	25.5	25.6	26.5	29.1	33.5	26.8	26.9	26.9	26.6	26.3	25.8	25.8
China	28.9	31.6	32.3	32.6	33.3	34.2	35.4	32.7	33.4	33.6	33.8	34.2	34.6	34.9	35.3
Colombia	31.3	31.3	30.0	29.3	34.7	32.9	33.6	34.3	34.1	34.6	34.8	34.4	33.6	32.8	32.3
Dominican Republic	17.0	16.7	17.0	17.1	16.4	17.9	22.1	18.5	18.5	18.9	18.1	17.9	17.6	17.4	17.1
Ecuador[1]	46.4	43.2	43.2	40.6	40.9	39.6	38.9	37.8	39.3	37.9	37.2	36.3	35.6	34.9	34.2
Egypt	33.9	31.3	31.0	30.6	28.6	26.9	25.7	25.5	24.7	22.8	28.9	29.4	28.8	27.8	27.1
Hungary	50.0	50.4	46.8	46.7	46.1	46.1	51.1	48.3	47.8	48.2	47.8	46.7	46.1	45.5	45.0
India	26.2	27.1	27.2	26.2	26.3	26.8	31.1	29.5	28.6	28.1	27.9	27.5	27.3	27.1	27.0
Indonesia	18.6	17.5	16.8	16.6	16.7	16.3	18.6	18.2	17.5	17.3	17.1	17.1	17.1	17.0	16.9
Iran	14.2	16.3	17.0	17.1	15.3	14.1	13.0	12.2	12.3	13.7	14.1	14.5	14.9	15.4	15.8
Kazakhstan	21.3	22.9	21.5	24.1	18.8	20.2	24.5	22.1	21.7	22.9	21.9	21.6	21.6	21.6	21.7
Kuwait	44.3	54.4	54.0	52.0	51.8	53.0	66.5	54.7	41.9	51.5	50.2	49.5	49.8	50.1	50.3
Lebanon	28.8	26.7	28.3	30.6	32.3	31.2	19.6	9.1	11.3	. . .	. . .	. . .	. . .	. . .	. . .
Malaysia	26.0	24.7	22.9	22.0	22.8	23.6	25.1	24.3	25.3	22.6	21.6	21.2	21.1	20.9	20.7
Mexico	26.9	26.6	26.5	25.0	25.0	25.2	27.8	26.8	28.5	27.7	29.1	26.3	26.1	26.1	25.9
Morocco	30.7	28.4	28.6	27.8	27.7	27.4	34.1	31.3	32.2	32.7	31.6	31.0	30.6	30.5	30.1
Oman	41.4	44.5	44.6	39.4	38.3	38.8	44.5	36.1	29.7	26.2	25.7	25.5	24.8	24.2	23.7
Pakistan	18.1	17.8	17.7	19.1	19.1	19.1	20.3	18.5	20.0	19.5	20.1	19.2	17.8	17.1	16.7
Peru	22.6	22.3	20.9	21.1	21.3	21.1	26.8	23.6	23.5	22.6	22.4	21.8	21.1	20.8	20.8
Philippines	16.8	17.8	19.0	19.5	20.9	21.7	25.9	27.2	25.9	24.9	25.1	25.0	24.9	24.5	24.5
Poland	42.9	41.7	41.3	41.4	41.4	41.9	48.2	44.1	43.5	47.0	47.0	47.0	47.0	46.4	46.2
Qatar	32.3	38.6	40.1	34.7	28.9	32.5	34.7	29.3	24.3	23.9	23.9	23.7	23.5	23.2	23.2
Romania	33.8	34.2	31.8	31.0	31.7	33.3	38.2	37.2	36.8	36.9	36.8	36.7	36.7	36.5	36.4
Russian Federation	34.9	35.3	36.6	34.8	32.6	33.8	39.2	34.8	36.0	36.1	35.8	35.0	34.7	34.0	33.5
Saudi Arabia	39.7	39.9	34.5	32.1	34.0	33.7	39.1	31.9	28.2	29.5	29.2	29.0	28.8	28.6	28.1
South Africa	29.3	30.2	29.9	29.9	30.2	31.4	34.6	32.6	32.5	33.2	33.0	33.7	33.6	33.6	33.8
Sri Lanka	17.2	19.3	18.2	17.9	17.5	19.5	21.0	20.0	18.5	. . .	. . .	. . .	. . .	. . .	. . .
Thailand	22.2	22.2	21.3	21.5	21.4	21.8	24.9	27.3	24.6	22.9	22.9	22.8	22.7	22.6	22.5
Türkiye	33.1	33.2	34.8	33.4	34.6	35.7	34.0	31.2	28.1	34.5	33.4	33.2	33.2	33.2	33.3
Ukraine	44.8	43.0	40.8	41.6	41.9	41.5	45.6	40.5	66.0	63.0	59.3	50.2	46.3	45.2	43.8
United Arab Emirates	32.2	27.2	32.8	28.1	26.7	28.4	31.1	26.4	22.9	26.8	26.7	26.7	26.7	26.6	26.5
Uruguay[2]	29.1	28.4	29.7	29.7	30.4	30.6	32.7	29.9	29.8	29.8	29.8	29.5	29.3	29.1	28.8
Venezuela	31.6	22.9	19.7	21.8	36.7	18.7	9.3	10.5	12.0	. . .	. . .	. . .	. . .	. . .	. . .

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: For country-specific details, see “Data and Conventions” in text and Table C. MENA = Middle East and North Africa.

[1] The data for Ecuador reflect expenditure of the nonfinancial public sector.

[2] Data are for the nonfinancial public sector, which includes central government, local government, social security funds, nonfinancial public corporations, and Banco de Seguros del Estado. The coverage of fiscal data was changed from the consolidated public sector to the nonfinancial public sector with the October 2019 submission. With this narrower coverage, the central bank balances are not included in the fiscal data. Historical data were also revised accordingly.

Table A15. Emerging Market and Middle-Income Economies: General Government Gross Debt, 2014–28
(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average[1]	40.5	44.3	49.9	52.0	53.3	55.9	65.9	65.1	65.3	68.3	70.1	72.3	74.3	76.2	78.1
Asia	43.4	45.0	51.8	55.1	56.5	59.8	70.2	71.4	74.7	79.1	82.3	85.3	88.0	90.7	93.3
Europe	28.2	30.3	31.2	29.4	29.0	28.5	37.0	34.7	32.3	35.9	36.4	37.3	37.6	37.9	38.0
Latin America	50.9	56.8	60.5	62.8	66.6	67.5	76.4	71.1	68.6	68.5	68.7	69.1	69.3	69.4	69.3
MENA	23.6	33.9	42.0	42.3	40.4	43.9	55.2	52.1	43.9	43.3	40.9	41.2	41.7	42.1	42.7
G20 Emerging	40.8	43.8	49.9	52.9	54.5	57.5	67.2	66.8	68.0	72.2	74.5	77.2	79.7	82.1	84.5
Algeria	7.7	8.7	20.4	27.2	38.4	46.0	52.0	62.8	55.6	55.1	58.8	63.9	68.1	72.2	75.8
Angola	39.8	57.1	75.7	69.3	93.0	113.6	138.9	86.8	66.7	84.9	77.1	67.9	61.0	54.3	48.0
Argentina	44.7	52.6	53.1	57.0	85.2	88.8	102.8	80.8	84.7	89.5	79.9	76.8	75.8	73.3	69.5
Belarus	38.8	53.0	53.5	53.2	47.5	41.0	47.5	41.2	41.3	44.1	44.2	43.3	41.5	39.2	36.8
Brazil	61.6	71.7	77.4	82.7	84.8	87.1	96.0	90.1	85.3	88.1	90.3	92.4	93.9	95.0	96.0
Bulgaria	26.3	25.4	27.0	22.9	20.1	18.3	23.2	22.5	21.8	21.0	22.9	25.2	26.8	28.2	29.5
Chile	15.0	17.4	21.1	23.7	25.8	28.3	32.4	36.3	38.0	38.4	41.2	42.3	42.6	42.3	42.1
China[2]	40.0	41.5	50.7	55.0	56.7	60.4	70.1	71.8	77.0	83.0	87.4	91.8	95.9	100.1	104.3
Colombia	43.3	50.4	49.8	49.4	53.6	52.4	65.7	64.0	60.4	55.0	55.1	55.4	54.8	53.9	53.2
Dominican Republic	44.9	44.7	46.6	48.9	50.5	53.6	71.5	63.2	59.5	59.8	59.4	58.4	57.4	56.0	54.4
Ecuador	28.0	35.2	44.6	47.0	49.1	51.4	60.9	62.3	57.7	55.5	53.8	52.6	51.0	49.4	47.7
Egypt	80.9	83.8	91.6	97.8	87.9	80.1	86.2	89.9	88.5	92.7	88.1	83.9	81.5	78.9	76.4
Hungary	76.5	75.8	74.9	72.1	69.1	65.3	79.3	76.6	73.3	68.7	65.7	64.1	62.1	60.3	57.6
India	67.1	69.0	68.9	69.7	70.4	75.0	88.5	83.8	81.0	81.9	82.3	82.2	81.7	81.2	80.5
Indonesia	24.7	27.0	28.0	29.4	30.4	30.6	39.7	41.1	40.1	39.0	38.6	38.2	37.9	37.5	37.2
Iran	12.6	37.0	47.9	45.0	42.9	46.7	48.3	42.4	34.1	30.6	30.5	32.2	33.8	35.2	36.1
Kazakhstan	14.5	21.9	19.7	19.9	20.3	19.9	26.4	25.1	23.5	23.4	23.6	25.7	28.1	30.1	32.2
Kuwait	3.4	4.7	9.9	20.5	15.1	11.6	11.7	8.6	3.1	3.4	3.1	5.8	9.4	11.8	16.9
Lebanon	138.4	140.8	146.4	150.0	155.1	172.3	150.6	349.9	283.2	. . .	. . .	. . .	. . .	. . .	. . .
Malaysia	55.4	57.0	55.8	54.4	55.6	57.1	67.7	69.2	65.6	66.9	66.9	67.0	67.5	68.6	69.5
Mexico	47.1	51.0	55.0	52.5	52.2	51.9	58.5	56.9	54.1	52.7	54.7	55.1	55.5	55.9	56.3
Morocco	58.6	58.4	60.1	60.3	60.5	60.3	72.2	69.5	71.5	69.7	69.1	68.7	68.4	67.8	66.9
Oman	4.0	13.9	29.3	40.1	44.7	52.5	67.9	61.3	40.0	38.2	34.0	31.9	30.3	29.0	28.0
Pakistan	57.8	57.9	60.8	60.9	64.8	77.5	79.6	73.5	76.2	76.6	72.2	70.4	68.3	66.6	64.1
Peru	20.6	24.0	24.3	25.2	26.0	26.9	35.0	36.4	34.3	33.9	34.0	33.5	32.7	31.9	31.1
Philippines	40.3	39.7	37.4	38.1	37.1	37.0	51.6	57.0	57.5	57.6	57.7	57.4	56.4	54.8	52.9
Poland	51.4	51.3	54.5	50.8	48.7	45.7	57.2	53.6	49.1	49.8	52.2	53.9	56.0	57.4	58.6
Qatar	24.9	35.5	46.7	51.6	52.2	62.1	72.6	58.4	42.4	41.4	38.3	36.3	34.9	33.1	32.3
Romania	40.5	39.4	39.5	37.1	36.2	36.6	49.4	51.7	50.5	51.0	52.7	55.2	57.1	59.1	61.1
Russian Federation	15.1	15.3	14.8	14.3	13.6	13.7	19.2	16.5	18.9	21.2	21.8	21.7	20.9	19.8	18.2
Saudi Arabia	1.5	5.7	12.7	16.5	17.6	21.6	31.0	28.8	23.8	24.1	22.4	20.7	19.2	17.7	16.9
South Africa	43.3	45.2	47.1	48.6	51.5	56.1	68.9	68.8	71.1	73.7	75.8	78.8	81.6	84.2	86.7
Sri Lanka	69.6	76.3	75.0	72.3	83.6	82.6	96.7	102.7	115.5	. . .	. . .	. . .	. . .	. . .	. . .
Thailand	43.3	42.6	41.7	41.8	41.9	41.1	49.4	58.4	60.5	61.4	62.9	62.6	62.0	61.5	60.7
Türkiye	28.4	27.3	27.9	27.9	30.0	32.6	39.6	41.8	31.7	34.4	31.9	32.2	31.5	31.6	32.2
Ukraine	70.3	79.3	79.5	71.6	60.3	50.4	60.5	48.9	78.5	88.1	98.6	100.7	99.5	98.4	94.6
United Arab Emirates	13.8	16.1	19.3	21.9	21.3	26.8	41.1	35.9	31.1	29.4	28.7	28.3	27.8	27.4	26.9
Uruguay[3]	51.1	57.8	56.4	55.8	58.0	59.8	68.1	63.4	59.3	61.6	61.4	61.7	61.6	61.6	61.3
Venezuela	84.9	129.8	138.4	133.6	174.6	205.1	327.7	248.4	159.5	. . .	. . .	. . .	. . .	. . .	. . .

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see “Fiscal Policy Assumptions” in text).

Note: For country-specific details, see “Data and Conventions” in text and Table C. MENA = Middle East and North Africa.

[1] The average does not include the debt incurred by the European Union and used to finance the grants portion of the NextGenerationEU package. This totaled €58 billion (0.4 percent of EU GDP) as of December 31, 2021, and €158 billion (1 percent of EU GDP) as of February 16, 2023. Debt incurred by the European Union and used to on-lend to member states is included within member state debt data and regional aggregates.

[2] China's deficit and public debt numbers presented in this table cover a narrower perimeter of the general government than IMF staff's estimates in China Article IV reports (see IMF 2023 for a reconciliation of the two estimates).

[3] Data are for the nonfinancial public sector, which includes central government, local government, social security funds, nonfinancial public corporations, and Banco de Seguros del Estado. The coverage of fiscal data was changed from the consolidated public sector to the nonfinancial public sector with the October 2019 submission. With this narrower coverage, the central bank balances are not included in the fiscal data. Historical data were also revised accordingly.

Table A16. Emerging Market and Middle-Income Economies: General Government Net Debt, 2014–28
(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average[1]	24.1	28.5	34.1	35.5	36.3	38.0	45.4	45.0	42.4	42.8	43.0	43.6	44.1	44.5	44.7
Asia	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Europe	29.1	28.2	30.3	28.9	29.2	28.9	35.7	36.2	30.6	32.4	32.2	32.8	33.8	34.2	34.3
Latin America	31.4	34.5	39.9	42.1	42.6	43.8	50.8	48.3	48.7	49.7	51.6	52.6	53.3	54.0	54.5
MENA	–3.0	12.6	26.9	27.6	28.9	33.2	43.2	45.5	37.0	36.1	33.3	33.6	33.9	33.9	34.1
G20 Emerging	22.9	25.7	31.6	34.6	35.4	36.9	43.9	43.3	40.5	42.0	42.9	43.6	44.1	44.4	44.7
Algeria	–21.8	–7.6	13.3	21.6	25.7	30.5	43.8	51.7	41.2	48.9	55.6	60.7	65.0	68.4	71.3
Angola	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Argentina	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Belarus	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Brazil	32.6	35.6	46.1	51.4	52.8	54.7	61.4	55.8	57.1	60.7	63.7	66.2	68.0	69.4	70.8
Bulgaria	13.1	15.4	11.3	10.3	9.0	8.4	13.3	12.7	11.2	11.4	13.8	16.4	18.3	20.1	21.7
Chile	–4.4	–3.5	0.9	4.4	5.7	8.0	13.3	20.1	19.6	21.2	22.2	22.5	22.2	21.5	20.8
China[2]	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Colombia	32.9	42.1	38.6	38.6	43.1	43.1	54.7	54.1	54.9	52.6	50.8	49.6	49.1	48.8	48.5
Dominican Republic	37.6	37.2	38.5	40.3	41.4	43.4	57.5	49.5	46.6	46.8	46.4	45.5	44.5	43.1	41.5
Ecuador	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Egypt	73.2	75.3	81.6	86.6	80.7	74.6	80.6	85.2	83.9	88.0	83.4	79.2	76.8	74.2	71.8
Hungary	70.3	70.5	67.9	65.2	62.1	58.4	72.3	69.6	66.4	61.8	58.8	57.1	55.2	53.3	50.7
India	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Indonesia	20.4	22.0	23.5	25.3	26.7	27.0	36.1	37.9	37.3	36.4	36.2	36.0	35.8	35.6	35.4
Iran	–3.4	21.6	36.4	32.9	31.5	36.9	40.3	36.1	28.7	25.6	25.6	27.0	28.5	29.8	30.7
Kazakhstan	–19.1	–30.8	–23.8	–15.8	–15.8	–13.9	–8.6	–3.3	–1.2	–0.1	0.2	0.5	1.1	2.0	3.0
Kuwait	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Lebanon	130.0	134.4	140.7	144.4	150.8	167.1	147.9	346.4	283.9	…	…	…	…	…	…
Malaysia	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Mexico	41.1	44.9	47.2	44.5	43.6	43.3	50.2	49.3	48.0	46.6	48.7	49.1	49.4	49.9	50.2
Morocco	58.1	57.8	59.6	59.9	60.2	60.0	71.6	68.9	71.1	69.3	68.6	68.3	68.0	67.4	66.5
Oman	–39.3	–37.0	–24.2	–10.4	6.4	11.2	27.7	24.9	12.9	6.9	2.3	0.6	–0.9	–1.8	–1.4
Pakistan	52.9	53.3	55.1	55.9	59.9	70.2	72.9	66.0	69.9	71.6	68.3	67.0	65.3	63.9	61.8
Peru	2.7	5.3	6.9	8.7	10.2	11.1	21.0	19.8	19.9	20.7	21.5	21.5	20.9	20.1	19.4
Philippines	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Poland	45.4	46.4	47.9	44.4	41.5	38.5	44.9	40.7	37.2	39.1	42.1	44.3	46.7	48.3	49.6
Qatar	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Romania	28.4	28.3	26.8	25.9	26.2	28.6	37.8	40.6	39.1	40.1	42.0	44.8	46.9	49.1	51.2
Russian Federation	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Saudi Arabia	–46.4	–35.1	–16.6	–7.4	–0.1	4.7	15.1	17.0	10.0	9.5	8.8	8.1	7.1	5.9	5.1
South Africa	38.1	41.0	42.1	43.8	46.6	50.6	62.1	63.0	66.4	71.2	74.2	77.5	80.5	83.1	85.7
Sri Lanka	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Thailand	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Türkiye	23.7	22.8	23.3	22.1	24.0	25.5	30.2	33.8	23.8	27.9	26.0	25.3	25.2	24.3	23.2
Ukraine	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
United Arab Emirates	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Uruguay[3]	40.8	44.4	44.3	44.2	46.7	50.0	57.3	53.3	50.5	52.9	52.8	53.2	53.3	53.3	53.0
Venezuela	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see "Fiscal Policy Assumptions" in text).

Note: For country–specific details, see "Data and Conventions" in text and Table C. MENA = Middle East and North Africa.

[1] The average does not include the debt incurred by the European Union and used to finance the grants portion of the NextGenerationEU package. This totaled €58 billion (0.4 percent of EU GDP) as of December 31, 2021, and €158 billion (1 percent of EU GDP) as of February 16, 2023. Debt incurred by the European Union and used to on-lend to member states is included within member state debt data and regional aggregates.

[2] China's deficit and public debt numbers presented in this table cover a narrower perimeter of the general government than IMF staff's estimates in China Article IV reports (see IMF 2023 for a reconciliation of the two estimates).

[3] Data are for the nonfinancial public sector, which includes central government, local government, social security funds, nonfinancial public corporations, and Banco de Seguros del Estado. The coverage of fiscal data was changed from the consolidated public sector to the nonfinancial public sector with the October 2019 submission. With this narrower coverage, the central bank balances are not included in the fiscal data. Historical data were also revised accordingly.

Table A17. Low–Income Developing Countries: General Government Overall Balance, 2014–28

(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	–3.1	–3.8	–3.7	–3.6	–3.3	–3.5	–5.0	–4.4	–3.8	–3.6	–3.3	–3.2	–3.2	–3.2	–3.2
Oil Producers	–2.9	–4.6	–5.3	–5.4	–4.1	–4.5	–5.3	–5.6	–5.0	–4.7	–4.0	–4.1	–4.3	–4.5	–4.8
Asia	–3.5	–3.8	–3.2	–3.1	–2.8	–3.0	–4.3	–3.5	–2.5	–3.3	–3.4	–3.5	–3.6	–3.5	–3.5
Latin America	–2.7	–1.2	–0.6	–0.7	–1.0	–0.6	–3.4	–2.5	0.3	–1.2	–1.2	–1.2	–1.2	–1.0	–1.1
Sub–Saharan Africa	–3.3	–4.1	–4.5	–4.5	–4.0	–4.0	–5.8	–5.5	–5.1	–4.0	–3.4	–3.2	–3.2	–3.2	–3.2
Others	–1.7	–3.1	–2.5	–2.3	–1.9	–3.0	–3.5	–2.0	–2.9	–3.8	–3.0	–2.5	–2.2	–2.2	–2.0
Afghanistan	–1.7	–1.4	0.1	–0.7	1.6	–1.1	–2.2	–0.3	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bangladesh	–2.6	–3.3	–3.2	–4.2	–4.1	–5.4	–4.8	–3.6	–4.1	–4.5	–4.5	–4.5	–5.0	–5.0	–5.0
Benin	–1.7	–5.6	–4.3	–4.2	–3.0	–0.5	–4.7	–5.7	–5.6	–4.3	–3.7	–2.9	–2.9	–2.9	–2.9
Burkina Faso	–1.7	–2.1	–3.1	–6.9	–4.4	–3.4	–5.1	–7.4	–10.7	–6.6	–5.6	–4.7	–3.8	–3.0	–3.0
Cambodia	–1.6	–0.6	–0.3	–0.8	0.7	3.0	–3.4	–7.1	–0.9	–4.5	–3.0	–2.9	–2.7	–2.6	–2.7
Cameroon	–4.1	–4.2	–5.9	–4.7	–2.4	–3.2	–3.2	–3.0	–1.1	–0.8	–0.6	–0.3	–0.7	–1.0	–1.0
Chad	–4.2	–4.4	–1.9	–0.2	1.9	–0.1	1.6	–2.0	5.1	8.3	0.8	1.7	1.5	2.4	1.7
Congo, Democratic Republic of the	0.0	–0.4	–0.5	1.3	–1.1	–2.4	–3.3	–2.0	–0.8	–2.0	–2.0	–2.4	–1.8	–2.4	–1.8
Congo, Republic of	–10.7	–17.8	–14.5	–5.6	5.2	4.3	–1.1	1.6	8.9	4.1	5.0	3.6	2.7	3.4	3.8
Côte d'Ivoire	–1.6	–2.0	–3.0	–3.3	–2.9	–2.2	–5.4	–4.9	–6.8	–5.2	–4.1	–3.0	–3.0	–2.8	–2.8
Ethiopia	–2.6	–1.9	–2.3	–3.2	–3.0	–2.5	–2.8	–2.8	–4.2	–2.7	–2.0	–2.5	–3.0	–3.0	–3.0
Ghana	–7.8	–4.0	–6.7	–4.0	–6.8	–7.5	–17.4	–12.0	–11.2	–4.6	–4.1	–3.5	–3.0	–2.6	–2.8
Guinea	–3.2	–6.6	–0.1	–2.1	–1.1	–0.3	–3.1	–1.8	–0.7	–2.3	–2.4	–2.3	–2.4	–2.6	–2.2
Haiti	–3.6	–1.5	0.1	–0.3	–1.1	–2.0	–2.5	–2.6	–2.1	–1.5	–1.8	–1.8	–1.9	–2.0	–2.0
Honduras	–2.9	–0.8	–0.4	–0.4	0.2	0.1	–4.5	–3.1	1.6	–1.9	–1.7	–1.5	–1.4	–1.0	–1.1
Kenya	–5.8	–6.7	–7.5	–7.4	–6.9	–7.4	–8.1	–7.2	–5.8	–4.7	–4.1	–3.7	–3.6	–3.8	–3.8
Kyrgyz Republic	–3.1	–2.5	–5.8	–3.7	–0.6	–0.1	–3.1	–0.7	–0.3	–1.8	–3.3	–3.1	–3.2	–3.4	–3.6
Lao P.D.R.	–3.1	–5.6	–4.9	–5.5	–4.7	–3.3	–5.6	–1.3	–1.6	–3.4	–3.5	–3.4	–3.5	–3.0	–2.9
Madagascar	–2.0	–2.9	–1.1	–2.1	–1.3	–1.4	–3.9	–2.6	–6.4	–3.9	–3.4	–5.1	–4.0	–4.5	–4.1
Malawi	–3.1	–4.2	–4.9	–5.2	–4.3	–4.5	–8.2	–8.6	–9.3	–6.8	–8.0	–7.5	–5.0	–4.3	–3.0
Mali	–2.9	–1.8	–3.9	–2.9	–4.7	–1.7	–5.4	–4.8	–4.8	–4.8	–4.4	–3.7	–3.0	–3.0	–3.0
Moldova	–1.6	–1.9	–1.5	–0.7	–0.9	–1.5	–5.3	–2.6	–3.2	–6.0	–4.6	–3.8	–3.4	–3.1	–2.6
Mozambique	–9.9	–6.7	–5.1	–2.0	–5.6	1.7	–5.4	–3.6	–5.0	–2.8	–2.2	–1.0	–0.5	0.7	2.1
Myanmar	–1.3	–2.8	–3.9	–2.9	–3.4	–3.9	–5.6	–11.0	–5.1	–4.5	–4.6	–4.6	–4.2	–3.7	–3.4
Nepal	1.3	0.6	1.2	–2.7	–5.8	–5.0	–5.4	–4.0	–3.2	–5.9	–4.9	–4.3	–3.9	–3.3	–2.9
Nicaragua	–1.2	–1.5	–1.8	–1.6	–3.0	–0.3	–2.3	–1.2	0.8	0.8	0.4	0.4	0.4	0.4	0.4
Niger	–6.1	–6.7	–4.5	–4.1	–3.0	–3.6	–4.8	–5.9	–6.8	–4.9	–4.1	–3.0	–3.0	–3.0	–3.0
Nigeria	–2.4	–3.8	–4.6	–5.4	–4.3	–4.7	–5.6	–6.0	–5.6	–5.4	–4.5	–4.5	–4.7	–5.0	–5.3
Papua New Guinea	–6.3	–4.5	–4.7	–2.5	–2.6	–4.4	–8.9	–6.8	–5.3	–4.4	–4.0	–2.5	–1.4	–0.2	0.0
Rwanda	–3.9	–2.7	–2.3	–2.5	–2.6	–5.1	–9.5	–7.0	–5.8	–5.0	–7.3	–4.0	–3.3	–3.3	–3.3
Senegal	–3.9	–3.7	–3.3	–3.0	–3.7	–3.9	–6.4	–6.3	–6.6	–5.0	–3.9	–3.3	–2.6	–2.4	–3.0
Sudan	–4.7	–3.9	–3.9	–6.1	–7.9	–10.8	–5.9	–0.3	–2.5	–4.2	–2.7	–1.4	–1.7	–1.3	–0.1
Tajikistan	0.8	–2.0	–9.0	–5.7	–2.7	–2.1	–4.3	–0.7	–0.2	–2.5	–2.5	–2.5	–2.5	–2.5	–2.5
Tanzania	–2.9	–3.2	–2.1	–1.2	–1.9	–2.0	–2.5	–3.4	–3.7	–3.3	–2.6	–2.5	–2.5	–2.5	–2.5
Uganda	–2.7	–2.5	–2.6	–3.6	–3.0	–4.8	–7.5	–7.5	–5.8	–4.2	–2.7	–2.4	–2.1	–1.1	1.2
Uzbekistan	1.9	–0.3	0.7	1.1	2.0	–0.3	–3.3	–4.6	–4.2	–4.6	–3.9	–3.3	–2.8	–2.8	–2.9
Vietnam	–5.0	–5.0	–3.2	–2.0	–1.0	–0.4	–2.9	–1.4	0.3	–1.3	–1.7	–2.1	–2.1	–2.1	–2.0
Yemen	–4.1	–8.7	–8.5	–4.9	–7.8	–5.9	–4.5	–0.9	–2.6	–2.7	0.0	–0.9	–0.6	–0.5	–0.1
Zambia	–5.4	–8.9	–5.7	–7.5	–8.3	–9.4	–13.8	–8.1	–7.7	–6.0	–4.6	–3.4	–4.4	–2.2	–1.2
Zimbabwe	–1.1	–1.8	–6.6	–10.6	–5.4	–0.9	0.8	–2.2	–2.0	–4.1	–3.2	–2.7	–2.2	–2.2	–2.1

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see "Fiscal Policy Assumptions" in text).

Note: For country–specific details, see "Data and Conventions" in text and Table D.

Table A18. Low-Income Developing Countries: General Government Primary Balance, 2014–28
(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	–1.9	–2.5	–2.3	–2.2	–1.7	–1.9	–3.2	–2.5	–1.8	–1.8	–1.4	–1.3	–1.3	–1.3	–1.2
Oil Producers	–1.6	–3.1	–3.7	–4.1	–2.5	–2.8	–3.3	–3.3	–2.3	–2.1	–1.2	–1.3	–1.5	–1.6	–1.7
Asia	–2.0	–2.3	–1.7	–1.7	–1.3	–1.6	–2.7	–1.9	–0.9	–1.7	–1.9	–2.0	–2.1	–2.0	–2.0
Latin America	–2.4	–0.7	–0.1	–0.2	–0.4	0.2	–2.6	–1.7	1.2	–0.3	–0.3	–0.3	–0.3	–0.2	–0.2
Sub-Saharan Africa	–2.2	–2.8	–2.9	–2.8	–2.0	–2.0	–3.7	–3.1	–2.6	–1.6	–0.9	–0.8	–0.8	–0.8	–0.7
Others	–0.4	–1.8	–1.6	–2.0	–1.7	–2.7	–3.1	–1.8	–2.5	–3.4	–2.5	–2.0	–1.7	–1.6	–1.5
Afghanistan	–1.7	–1.3	0.2	–0.6	1.7	–1.0	–2.2	–0.3	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bangladesh	–0.9	–1.6	–1.6	–2.6	–2.5	–3.7	–3.0	–1.6	–2.2	–2.4	–2.6	–2.6	–3.2	–3.1	–3.1
Benin	–1.4	–5.0	–3.4	–2.8	–1.4	1.1	–2.7	–3.5	–3.9	–2.7	–2.1	–1.3	–1.4	–1.4	–1.4
Burkina Faso	–1.1	–1.5	–2.2	–6.0	–3.3	–2.1	–3.8	–5.7	–8.7	–4.5	–3.0	–2.0	–1.2	–0.4	–0.4
Cambodia	–1.3	–0.3	0.1	–0.5	1.0	3.3	–3.0	–6.7	–0.5	–4.3	–2.8	–2.7	–2.5	–2.3	–2.4
Cameroon	–3.7	–3.9	–5.2	–3.9	–1.5	–2.2	–2.3	–2.0	–0.4	0.3	0.4	0.7	0.3	0.0	0.0
Chad	–3.6	–2.7	0.1	1.3	3.0	0.8	2.7	–0.8	6.6	9.9	2.1	3.2	2.5	3.3	2.6
Congo, Democratic Republic of the	0.3	–0.1	–0.2	1.6	–0.7	–2.2	–3.0	–1.7	–0.4	–1.7	–1.7	–2.2	–1.5	–2.2	–1.3
Congo, Republic of	–10.6	–17.2	–12.7	–4.0	7.0	7.2	0.1	3.7	11.5	6.6	7.4	6.1	5.4	5.9	6.2
Côte d'Ivoire	–0.7	–0.9	–1.7	–2.0	–1.6	–0.8	–3.6	–3.0	–4.6	–3.0	–1.9	–0.8	–0.8	–0.6	–0.7
Ethiopia	–2.2	–1.5	–1.8	–2.8	–2.5	–2.0	–2.4	–2.2	–3.5	–2.1	–1.4	–1.7	–1.8	–1.6	–1.5
Ghana	–3.3	0.9	–1.5	1.2	–1.4	–2.0	–11.2	–4.8	–3.7	–0.5	0.5	1.5	1.5	1.5	1.5
Guinea	–2.2	–5.7	0.9	–1.2	–0.3	0.2	–2.4	–1.2	0.1	–1.6	–1.5	–1.4	–1.5	–1.6	–1.2
Haiti	–3.4	–1.4	0.3	–0.2	–0.9	–1.7	–2.2	–2.2	–1.7	–1.2	–1.6	–1.6	–1.7	–1.7	–1.8
Honduras	–2.6	0.0	0.2	0.2	0.8	0.8	–3.6	–2.1	2.6	–0.7	–0.4	–0.2	–0.1	0.1	0.1
Kenya	–3.4	–4.2	–4.6	–4.2	–3.4	–3.8	–4.2	–3.1	–1.4	–0.1	0.6	0.8	0.9	0.8	0.8
Kyrgyz Republic	–2.3	–1.7	–4.9	–2.9	0.4	0.8	–2.1	0.0	0.8	–0.8	–2.2	–1.7	–1.5	–1.5	–1.5
Lao P.D.R.	–2.4	–4.8	–4.0	–4.7	–3.5	–2.0	–4.1	–0.3	0.0	0.3	0.3	0.2	0.2	0.1	0.0
Madagascar	–1.5	–2.2	–0.4	–1.4	–0.6	–0.7	–3.2	–2.0	–5.9	–2.9	–2.5	–4.2	–3.3	–3.8	–3.4
Malawi	0.0	–1.9	–1.8	–2.4	–1.6	–1.5	–5.0	–4.6	–4.6	–2.2	–0.9	0.7	2.7	2.5	3.0
Mali	–2.3	–1.2	–3.3	–2.0	–3.9	–0.7	–4.2	–3.5	–3.3	–3.3	–2.9	–2.2	–1.5	–1.5	–1.4
Moldova	–1.1	–1.2	–0.4	0.5	0.0	–0.7	–4.5	–1.8	–2.2	–4.2	–3.4	–2.6	–2.3	–2.0	–1.5
Mozambique	–8.9	–5.5	–2.7	1.0	–1.2	5.0	–2.3	–0.9	–2.1	0.4	0.8	1.7	1.8	2.8	3.9
Myanmar	–0.1	–1.6	–2.6	–1.5	–1.6	–2.4	–4.0	–8.9	–2.5	–1.9	–2.0	–2.1	–1.6	–1.1	–0.9
Nepal	1.8	0.9	1.5	–2.4	–5.4	–4.5	–4.7	–3.2	–2.3	–4.6	–3.3	–2.7	–2.2	–1.6	–1.2
Nicaragua	–0.9	–1.1	–1.2	–0.7	–1.9	1.0	–1.1	0.0	2.1	1.8	1.6	1.5	1.5	1.5	1.4
Niger	–5.8	–6.3	–3.8	–3.4	–2.1	–2.6	–3.8	–4.8	–5.5	–3.6	–2.8	–1.7	–1.8	–1.8	–1.8
Nigeria	–1.5	–2.7	–3.4	–4.1	–2.6	–3.0	–3.5	–3.6	–2.8	–2.7	–1.5	–1.5	–1.7	–1.9	–2.0
Papua New Guinea	–4.6	–2.8	–2.8	–0.4	–0.2	–1.9	–6.2	–4.4	–3.0	–2.2	–1.0	0.3	1.4	2.6	1.7
Rwanda	–3.1	–1.8	–1.3	–1.5	–1.4	–3.8	–7.9	–5.2	–3.9	–2.3	–4.6	–1.4	–0.8	–0.9	–2.1
Senegal	–2.6	–2.1	–1.6	–1.1	–1.7	–1.9	–4.4	–4.3	–4.4	–2.3	–1.3	–1.1	–0.3	–0.2	–0.8
Sudan	–3.9	–3.2	–3.5	–5.6	–7.7	–10.6	–5.9	–0.2	–2.3	–4.1	–2.2	–0.9	–1.0	0.0	0.4
Tajikistan	1.4	–1.5	–8.3	–5.2	–1.6	–1.2	–3.4	0.2	0.5	–1.7	–1.4	–1.3	–1.3	–1.3	–1.4
Tanzania	–1.6	–1.7	–0.6	0.4	–0.2	–0.3	–0.9	–1.8	–1.9	–1.3	–0.6	–0.5	–0.5	–0.5	–0.5
Uganda	–1.5	–1.1	–0.6	–1.5	–1.2	–2.7	–5.2	–4.6	–2.8	–1.1	0.2	0.4	0.7	1.9	3.7
Uzbekistan	1.8	–0.4	0.6	0.9	1.6	–0.5	–3.4	–4.8	–4.3	–4.5	–3.7	–3.1	–2.6	–2.5	–2.5
Vietnam	–3.7	–3.4	–1.6	–0.4	0.5	1.0	–1.5	–0.2	1.3	–0.4	–0.8	–1.2	–1.2	–1.1	–1.0
Yemen	1.5	–2.6	–3.2	–4.7	–7.8	–5.7	–2.6	0.2	–1.6	–1.9	0.7	–0.3	0.0	0.0	0.3
Zambia	–3.2	–6.0	–2.2	–3.5	–3.5	–2.5	–7.8	–2.0	–1.6	0.2	1.3	1.9	1.1	1.9	2.2
Zimbabwe	–0.4	–0.9	–6.0	–9.7	–4.4	–0.5	0.9	–1.7	–1.9	–3.3	–2.4	–2.0	–1.5	–1.4	–1.4

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see "Fiscal Policy Assumptions" in text).
Note: "Primary balance" is defined as the overall balance, excluding net interest payments. For country-specific details, see "Data and Conventions" in text and Table D.

Table A19. Low-Income Developing Countries: General Government Revenue, 2014–28
(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	15.6	14.2	13.7	14.2	14.8	14.5	13.8	14.3	14.9	14.9	15.4	15.6	15.7	15.7	15.7
Oil Producers	12.8	8.2	6.1	7.1	9.2	8.6	7.3	8.1	9.9	10.3	10.6	10.5	10.1	9.7	9.4
Asia	15.8	15.5	15.0	14.9	15.3	14.9	14.3	14.5	14.5	14.1	14.6	14.9	15.2	15.3	15.4
Latin America	19.9	20.6	21.8	21.4	20.9	21.1	19.7	20.0	20.5	19.4	19.6	19.8	19.9	19.9	20.0
Sub-Saharan Africa	14.3	12.3	11.7	12.7	13.2	13.1	12.3	13.1	13.7	14.2	14.6	14.5	14.5	14.4	14.3
Others	21.2	18.0	17.1	17.0	20.4	20.0	18.7	19.8	24.2	22.6	23.4	24.5	25.2	25.6	26.1
Afghanistan	23.7	24.6	28.2	27.1	30.6	26.9	25.7	17.5	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bangladesh	9.1	8.2	8.4	8.1	8.9	8.1	8.5	9.4	8.9	8.3	8.8	9.3	9.9	10.0	10.2
Benin	12.6	12.6	11.1	13.6	13.6	14.1	14.4	14.1	14.3	14.6	15.2	15.6	16.0	16.5	16.9
Burkina Faso	19.2	18.3	18.6	19.2	19.8	19.9	19.1	20.3	21.7	19.9	20.4	21.3	21.8	22.2	22.6
Cambodia	20.1	19.6	20.8	21.6	23.7	26.8	23.9	21.6	23.9	22.6	23.6	24.1	24.2	24.2	23.9
Cameroon	16.0	15.8	14.3	14.5	15.5	15.4	13.4	14.0	16.0	15.8	15.5	15.3	15.3	15.3	15.3
Chad	17.8	14.0	12.4	14.6	15.3	14.2	21.1	16.8	23.9	27.3	18.5	19.4	18.1	18.7	17.7
Congo, Democratic Republic of the	17.3	15.9	13.5	11.3	10.9	11.0	9.5	13.6	16.6	14.4	15.6	15.8	16.3	16.6	17.2
Congo, Republic of	37.8	23.5	24.3	21.0	23.0	24.5	20.0	22.6	31.8	26.6	26.1	25.3	24.8	24.5	24.1
Côte d'Ivoire	13.6	14.5	14.6	14.8	14.7	15.1	15.0	15.8	15.3	16.5	17.1	17.4	18.0	17.9	18.0
Ethiopia	14.9	15.4	15.6	14.7	13.1	12.8	11.7	11.0	8.5	7.7	8.1	8.5	8.7	8.9	9.0
Ghana	13.2	14.6	13.1	13.6	14.1	15.0	14.1	15.2	15.8	15.7	16.6	17.3	18.2	18.2	18.1
Guinea	17.0	15.2	16.0	15.3	14.9	14.7	14.0	13.9	13.2	13.3	13.9	14.6	15.0	15.3	15.3
Haiti	11.0	11.3	10.7	9.9	10.1	7.6	7.5	6.8	6.2	6.5	7.1	7.6	7.9	8.0	8.3
Honduras	24.7	25.2	27.0	26.5	26.4	25.8	23.4	25.3	25.5	24.9	25.3	25.6	25.6	25.6	25.5
Kenya	17.7	17.1	17.9	17.8	17.5	17.0	16.7	16.8	17.2	17.5	18.4	18.2	18.0	18.1	18.2
Kyrgyz Republic	35.4	35.6	33.1	33.3	32.5	30.8	29.0	31.4	36.5	32.7	32.0	31.7	31.4	31.2	31.0
Lao P.D.R.	21.9	20.2	16.0	16.3	16.2	15.4	13.0	15.0	14.9	15.1	15.1	15.1	15.1	15.0	14.9
Madagascar	10.6	10.2	12.4	12.8	13.0	13.9	12.4	11.1	10.9	15.0	13.8	13.7	14.5	14.3	14.3
Malawi	15.2	15.4	14.8	15.8	15.0	14.8	14.5	15.0	17.3	17.8	17.5	17.0	17.8	17.7	18.3
Mali	17.1	19.1	18.3	20.1	15.6	21.5	20.5	21.5	19.8	21.3	21.4	22.0	22.5	22.7	23.0
Moldova	31.8	30.0	28.6	30.3	30.7	30.5	31.4	32.0	33.2	32.7	31.8	32.0	33.0	32.9	33.0
Mozambique	30.4	26.0	23.9	27.1	25.8	29.9	27.5	27.4	27.3	27.4	26.4	26.9	27.5	26.5	26.0
Myanmar	22.5	21.4	19.6	17.9	17.6	16.3	16.0	13.1	13.2	13.9	14.2	14.5	14.8	15.0	15.3
Nepal	17.9	18.2	20.1	20.9	22.2	22.4	22.2	23.3	23.1	19.4	20.7	21.2	22.0	22.7	23.3
Nicaragua	23.3	23.8	24.9	25.6	24.6	27.4	26.7	29.1	29.3	27.8	27.3	27.2	27.3	27.2	27.2
Niger[1]	17.5	17.5	14.9	15.4	18.2	18.0	17.5	18.4	14.8	14.3	18.5	19.4	19.7	19.8	19.8
Nigeria	10.9	7.3	5.1	6.6	8.5	7.8	6.5	7.3	8.8	9.3	9.7	9.3	8.9	8.5	8.3
Papua New Guinea	20.8	18.3	16.1	15.9	17.7	16.3	14.7	15.0	16.7	17.4	18.6	18.8	18.8	19.0	19.1
Rwanda	23.6	23.9	22.9	22.6	23.8	23.1	23.9	24.6	23.9	22.8	22.5	23.9	24.4	24.4	23.8
Senegal	19.2	19.3	20.7	19.5	18.9	20.3	20.2	19.5	19.9	21.4	21.5	22.1	23.3	23.5	23.3
Sudan	8.8	8.5	6.1	6.7	8.9	7.8	4.8	9.5	15.2	5.4	10.7	13.9	13.5	16.5	18.1
Tajikistan	28.4	29.9	29.7	28.1	28.2	26.8	24.8	27.0	27.7	28.7	27.9	27.5	27.4	26.5	26.5
Tanzania	14.4	14.0	14.8	15.4	14.7	14.7	14.3	14.4	14.6	14.9	15.6	15.9	16.1	16.1	16.0
Uganda	10.8	12.5	12.4	12.7	13.2	13.5	13.9	14.1	14.0	15.3	16.2	17.1	18.2	19.1	20.4
Uzbekistan	26.8	24.3	24.0	23.5	26.8	26.8	25.5	25.9	30.9	29.7	29.3	29.6	29.9	30.1	30.4
Vietnam	17.7	19.2	19.1	19.6	19.5	19.4	18.4	18.7	19.0	18.4	18.6	18.8	19.0	19.2	19.4
Yemen	23.6	10.7	7.6	3.5	6.4	7.3	6.2	7.3	9.6	4.9	8.4	13.5	17.4	16.7	16.6
Zambia	18.9	18.8	18.2	17.5	19.4	20.4	20.3	22.3	20.0	21.2	22.0	22.1	21.8	21.9	22.2
Zimbabwe	19.3	18.7	17.0	18.1	14.8	10.8	13.3	15.4	16.7	17.0	17.5	18.0	18.5	18.5	18.6

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see "Fiscal Policy Assumptions" in text).
Note: For country-specific details, see "Data and Conventions" in text and Table D.
[1] These estimates and projections include grants.

Table A20. Low-Income Developing Countries: General Government Expenditure, 2014–28

(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	18.8	18.0	17.4	17.8	18.0	18.0	18.7	18.7	18.7	18.6	18.7	18.8	19.0	18.9	18.9
Oil Producers	15.7	12.7	11.4	12.5	13.3	13.0	12.6	13.7	14.8	15.0	14.6	14.6	14.4	14.2	14.2
Asia	19.2	19.3	18.2	18.0	18.1	17.9	18.6	18.0	16.9	17.4	18.0	18.4	18.8	18.8	18.9
Latin America	22.7	21.8	22.4	22.2	21.9	21.7	23.1	22.5	20.2	20.5	20.8	21.0	21.1	20.9	21.1
Sub-Saharan Africa	17.6	16.4	16.2	17.2	17.2	17.1	18.1	18.7	18.8	18.2	17.9	17.7	17.7	17.6	17.5
Others	22.9	21.1	19.6	19.3	22.2	22.9	22.2	21.8	27.1	26.4	26.4	27.1	27.5	27.8	28.1
Afghanistan	25.4	25.9	28.0	27.7	28.9	28.0	27.9	17.8	...	...	...	...	...	...	...
Bangladesh	11.7	11.5	11.6	12.2	13.0	13.6	13.3	13.0	13.0	12.7	13.3	13.8	14.9	15.0	15.2
Benin	14.2	18.2	15.4	17.8	16.6	14.6	19.1	19.9	19.9	18.9	18.9	18.5	18.9	19.4	19.8
Burkina Faso	20.9	20.4	21.7	26.1	24.2	23.2	24.3	27.8	32.3	26.5	26.0	26.0	25.6	25.2	25.6
Cambodia	21.7	20.3	21.1	22.4	23.0	23.8	27.3	28.6	24.8	27.1	26.7	27.0	26.9	26.7	26.7
Cameroon	20.1	20.1	20.2	19.2	18.0	18.7	16.6	16.9	17.1	16.6	16.1	15.6	16.0	16.3	16.3
Chad	22.0	18.3	14.4	14.9	13.3	14.3	19.5	18.8	18.8	19.0	17.8	17.6	16.6	16.3	16.0
Congo, Democratic Republic of the	17.3	16.3	13.9	10.0	12.0	13.3	12.8	15.6	17.4	16.4	17.6	18.3	18.1	19.0	19.0
Congo, Republic of	48.6	41.3	38.8	26.6	17.8	20.2	21.1	20.9	22.8	22.5	21.1	21.8	22.0	21.2	20.2
Côte d'Ivoire	15.2	16.5	17.6	18.1	17.6	17.3	20.4	20.7	22.1	21.8	21.2	20.4	21.0	20.8	20.8
Ethiopia	17.5	17.3	17.9	18.0	16.1	15.4	14.5	13.8	12.7	10.5	10.1	11.0	11.7	11.9	12.0
Ghana	21.0	18.6	19.9	17.6	20.9	22.5	31.5	27.2	27.1	20.3	20.7	20.8	21.2	20.8	20.9
Guinea	20.2	21.7	16.1	17.3	16.0	15.0	17.1	15.6	13.9	15.6	16.2	16.9	17.5	17.9	17.5
Haiti	14.6	12.7	10.5	10.2	11.3	9.6	10.0	9.3	8.3	8.0	8.9	9.4	9.8	10.0	10.3
Honduras	27.6	26.0	27.4	26.9	26.2	25.7	27.8	28.4	23.8	26.7	27.0	27.1	27.0	26.6	26.6
Kenya	23.4	23.8	25.3	25.2	24.5	24.4	24.8	24.0	23.0	22.2	22.5	21.9	21.6	21.9	22.0
Kyrgyz Republic	38.5	38.1	38.9	37.0	33.1	30.8	32.1	32.1	36.8	34.5	35.3	34.9	34.6	34.6	34.7
Lao P.D.R.	25.0	25.8	20.9	21.8	20.9	18.8	18.6	16.3	16.5	18.4	18.6	18.5	18.6	18.0	17.9
Madagascar	12.6	13.0	13.5	14.9	14.4	15.4	16.4	13.7	17.3	18.8	17.2	18.8	18.5	18.8	18.4
Malawi	18.3	19.5	19.7	21.0	19.4	19.3	22.7	23.6	26.7	24.6	25.5	24.5	22.8	22.0	21.3
Mali	20.0	20.9	22.3	22.9	20.3	23.1	25.9	26.3	24.6	26.1	25.8	25.7	25.5	25.7	26.0
Moldova	33.4	31.9	30.1	31.0	31.5	32.0	36.7	34.6	36.4	38.7	36.4	35.8	36.4	36.0	35.6
Mozambique	40.3	32.7	29.0	29.1	31.3	28.2	32.9	30.9	32.3	30.2	28.6	28.0	28.0	25.9	23.8
Myanmar	23.8	24.2	23.4	20.8	21.0	20.3	21.6	24.1	18.4	18.3	18.8	19.1	19.0	18.7	18.7
Nepal	16.6	17.7	19.0	23.6	28.0	27.3	27.6	27.2	26.3	25.3	25.7	25.6	25.9	26.0	26.1
Nicaragua	24.6	25.3	26.8	27.3	27.6	27.6	29.1	30.3	28.4	27.1	26.9	26.9	26.9	26.8	26.8
Niger	23.6	24.2	19.4	19.5	21.2	21.6	22.4	24.3	21.6	19.1	22.6	22.3	22.7	22.7	22.7
Nigeria	13.4	11.0	9.8	12.0	12.8	12.5	12.1	13.3	14.4	14.6	14.2	13.9	13.6	13.6	13.6
Papua New Guinea	27.1	22.8	20.9	18.4	20.3	20.7	23.5	21.8	22.0	21.9	22.5	21.3	20.3	19.2	19.2
Rwanda	27.5	26.6	25.1	25.1	26.4	28.2	33.5	31.6	29.7	27.8	29.8	28.0	27.6	27.7	27.1
Senegal	23.1	22.9	24.0	22.5	22.6	24.2	26.6	25.8	26.6	26.4	25.4	25.5	25.9	25.9	26.4
Sudan	13.5	12.4	10.0	12.8	16.8	18.7	10.7	9.7	17.7	9.6	13.4	15.3	15.2	17.8	18.2
Tajikistan	27.5	31.9	38.7	33.8	30.9	28.8	29.2	27.6	28.0	31.2	30.3	30.0	29.9	29.0	29.0
Tanzania	17.3	17.2	16.9	16.6	16.6	16.7	16.8	17.8	18.3	18.2	18.2	18.4	18.6	18.6	18.6
Uganda	13.6	15.1	15.0	16.3	16.2	18.3	21.4	21.5	19.8	19.5	19.0	19.5	20.4	20.2	19.2
Uzbekistan	24.9	24.6	23.3	22.4	24.8	27.1	28.7	30.5	35.0	34.3	33.2	32.9	32.7	32.9	33.2
Vietnam	22.8	24.2	22.2	21.5	20.5	19.8	21.3	20.1	18.8	19.7	20.3	20.8	21.0	21.3	21.4
Yemen	27.8	19.4	16.1	8.4	14.3	13.2	10.6	8.2	12.2	7.6	8.4	14.3	18.0	17.2	16.7
Zambia	24.3	27.6	23.9	25.0	27.7	29.8	34.1	30.4	27.6	27.2	26.6	25.5	26.1	24.1	23.4
Zimbabwe	20.4	20.5	23.7	28.7	20.2	11.7	12.5	17.5	18.7	21.1	20.7	20.7	20.7	20.7	20.7

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see "Fiscal Policy Assumptions" in text).

Note: For country-specific details, see "Data and Conventions" in text and Table D.

Table A21. Low-Income Developing Countries: General Government Gross Debt, 2014–28
(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	31.2	35.6	38.7	41.3	41.7	42.8	48.4	48.4	48.4	48.0	46.3	44.7	43.8	43.0	42.0
Oil Producers	20.7	24.6	28.9	31.3	32.3	33.8	38.9	40.0	42.1	42.1	43.6	41.8	41.0	40.5	40.3
Asia	36.0	36.7	37.2	36.9	36.9	37.0	39.1	40.9	40.0	40.2	39.8	39.4	39.4	39.2	39.1
Latin America	32.1	32.5	32.4	33.9	35.3	38.0	42.1	41.0	40.3	36.3	35.7	35.1	34.9	34.1	33.5
Sub-Saharan Africa	27.4	33.0	37.2	40.3	41.6	43.2	49.7	51.0	52.5	51.8	49.4	47.1	45.7	44.4	43.1
Others	38.6	45.1	51.3	65.7	67.7	70.6	89.7	74.1	67.5	69.6	64.4	60.3	57.3	55.9	52.3
Afghanistan	8.7	9.2	8.4	8.0	7.4	6.1	7.4	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bangladesh	28.7	28.2	27.7	28.3	29.6	32.0	34.5	35.6	37.9	39.4	39.7	39.9	40.5	41.2	41.9
Benin	22.3	30.9	35.9	39.6	41.1	41.2	46.1	50.3	54.2	53.0	52.4	51.4	50.5	49.7	49.0
Burkina Faso	26.1	31.3	32.9	33.7	38.2	41.5	43.3	55.4	58.3	61.2	61.2	61.4	60.9	60.0	58.8
Cambodia	31.9	31.2	28.9	30.0	28.4	28.2	34.4	35.9	34.8	35.3	35.5	35.0	35.3	35.5	36.2
Cameroon	20.7	31.6	32.1	36.5	38.3	41.6	44.9	46.8	45.5	41.9	39.6	37.2	35.7	34.6	33.5
Chad	38.2	42.5	50.0	48.7	46.2	51.6	55.9	57.4	48.8	43.2	38.7	34.9	32.7	31.2	30.0
Congo, Democratic Republic of the	15.7	16.0	18.8	18.5	14.8	14.8	16.5	15.9	14.5	13.3	11.1	9.1	7.5	6.1	4.8
Congo, Republic of	42.3	74.2	84.6	88.5	71.2	77.6	102.5	97.8	92.5	97.8	91.0	87.3	83.1	78.3	72.3
Côte d'Ivoire	26.7	29.2	31.1	32.6	35.3	37.5	46.3	50.9	56.8	56.8	57.0	56.1	55.3	54.7	54.0
Ethiopia	44.2	50.7	53.1	55.2	58.4	55.8	53.9	53.8	46.4	37.9	31.2	28.9	29.0	29.6	29.6
Ghana[1]	50.1	53.9	55.9	57.0	62.0	58.3	72.3	79.2	92.4	84.9	81.5	78.8	75.8	72.8	70.0
Guinea	35.2	44.4	43.0	41.9	39.3	38.6	47.8	41.5	33.1	31.6	31.5	31.6	29.9	29.6	29.2
Haiti	20.8	21.7	21.6	18.9	21.5	25.4	22.0	25.6	23.9	19.6	18.6	18.2	17.9	18.0	17.7
Honduras	42.8	42.3	40.3	43.6	43.5	43.8	51.7	49.8	49.1	46.3	46.6	46.5	47.0	46.2	45.9
Kenya	41.3	45.8	50.4	53.9	56.4	59.1	68.0	68.2	68.4	70.2	68.3	66.7	65.0	63.8	62.7
Kyrgyz Republic	53.6	67.1	59.1	58.8	54.8	48.8	63.6	56.2	49.2	47.0	46.1	46.0	46.1	46.8	47.9
Lao P.D.R.	53.5	53.1	54.5	57.2	60.6	69.1	76.0	92.4	128.5	121.7	118.7	114.7	111.1	107.1	103.1
Madagascar	37.8	44.1	40.3	40.1	42.9	41.3	52.2	52.0	55.1	54.0	53.5	54.2	54.8	55.9	56.5
Malawi	33.5	35.5	37.1	40.3	43.9	45.3	54.8	61.5	75.2	78.6	77.4	77.4	75.5	73.5	70.1
Mali	26.9	30.7	36.0	36.0	37.5	40.7	46.9	50.4	51.7	51.8	52.6	52.9	52.7	52.7	52.6
Moldova	35.0	42.4	39.2	34.9	31.8	28.8	36.6	32.6	32.6	35.1	38.4	37.4	36.9	36.8	35.9
Mozambique	64.3	87.4	126.2	104.1	106.7	99.0	120.0	104.9	95.5	89.7	92.4	90.2	87.5	74.6	61.1
Myanmar	35.2	36.4	38.3	38.5	40.4	38.8	39.3	65.5	60.0	57.5	59.3	61.2	63.0	62.1	60.7
Nepal	27.6	25.7	25.0	25.0	31.1	34.0	43.3	43.3	43.1	46.7	47.9	49.1	49.9	50.2	49.9
Nicaragua	28.7	28.9	30.9	33.8	37.4	41.1	47.3	46.2	43.9	41.5	40.2	38.9	37.6	35.9	33.9
Niger	22.1	29.9	32.8	36.5	37.0	39.8	45.0	51.3	50.3	48.7	46.3	45.2	44.5	44.0	43.5
Nigeria[2]	17.5	20.3	23.4	25.3	27.7	29.2	34.5	36.5	39.6	38.8	41.3	40.3	40.1	40.0	40.3
Papua New Guinea	26.9	29.9	33.7	32.5	36.7	40.2	48.7	52.2	48.4	50.6	48.7	47.2	45.1	42.6	41.8
Rwanda	28.3	32.4	36.5	41.3	45.0	49.9	65.6	66.7	61.1	63.3	72.1	73.7	72.2	70.6	67.2
Senegal[3]	42.4	44.5	47.5	61.1	61.5	63.6	69.2	73.3	76.6	81.0	72.1	67.6	66.2	64.7	62.5
Sudan	84.4	93.2	109.9	149.5	186.7	200.2	275.2	187.9	186.2	256.0	238.8	235.9	240.0	253.8	244.6
Tajikistan	27.9	35.0	42.2	46.3	46.6	43.5	51.8	42.1	32.6	33.5	32.9	32.1	31.4	30.7	30.2
Tanzania	36.1	39.2	39.8	40.7	40.5	39.1	39.8	42.1	42.3	42.6	41.8	40.3	38.8	37.4	36.0
Uganda	24.8	28.3	30.9	33.6	34.9	37.6	46.4	50.6	48.4	48.3	47.7	46.3	44.5	41.4	37.5
Uzbekistan	6.1	10.0	8.2	19.3	19.6	28.5	37.4	36.6	34.9	35.1	34.8	33.9	33.0	32.4	32.1
Vietnam	43.6	46.1	47.5	46.3	43.5	40.8	41.1	39.1	35.3	34.0	32.7	31.7	31.0	30.4	29.7
Yemen	48.9	57.1	75.3	84.0	89.5	94.6	89.5	74.4	66.0	66.4	56.1	45.6	38.0	32.9	28.5
Zambia	33.9	61.9	58.0	63.4	75.2	94.4	140.2	110.8	98.5	. . .	. . .	. . .	. . .	. . .	. . .
Zimbabwe	42.3	48.0	49.9	74.1	50.9	82.3	84.4	59.8	98.4	95.4	56.9	52.2	48.2	48.4	42.7

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see "Fiscal Policy Assumptions" in text).
Note: For country-specific details, see "Data and Conventions" in text and Table D.
[1] Ghana is in the process of restructuring its debt. Government debt projections are based on a pre-debt restructuring scenario.
[2] Debt includes overdrafts from the Central Bank of Nigeria and liabilities of the Asset Management Corporation of Nigeria.
[3] From 2017 onward, Senegal data include the whole of the public sector, whereas before 2017, only central government debt stock was taken into account.

Table A22. Low-Income Developing Countries: General Government Net Debt, 2014–28
(Percent of GDP)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Oil Producers	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Asia	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Latin America	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Sub-Saharan Africa	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Others	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Afghanistan	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bangladesh	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Benin	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Burkina Faso	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Cambodia	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Cameroon	19.1	27.6	30.5	33.3	35.9	39.5	43.0	45.4	43.9	40.1	37.0	33.8	31.7	30.2	28.9
Chad	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Congo, Democratic Republic of the	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Congo, Republic of	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Côte d'Ivoire	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Ethiopia	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Ghana[1]	45.3	49.8	50.9	51.9	60.7	58.3	72.3	79.2	92.4	84.9	81.5	78.8	75.8	72.8	70.0
Guinea	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Haiti	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Honduras	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Kenya	34.8	39.7	47.5	48.1	50.8	54.1	63.0	64.2	65.3	67.5	65.9	64.5	63.0	62.0	61.0
Kyrgyz Republic	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Lao P.D.R.	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Madagascar	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Malawi	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Mali	19.7	23.1	30.0	31.1	34.1	34.6	40.4	43.4	47.7	46.8	47.0	47.5	47.7	48.1	48.4
Moldova	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Mozambique	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Myanmar	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Nepal	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Nicaragua	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Niger	17.2	25.9	29.5	32.3	34.1	35.9	41.0	45.1	45.2	46.2	44.7	44.1	43.8	43.6	43.4
Nigeria[2]	13.8	15.9	19.0	20.9	23.5	25.5	34.1	36.4	39.4	38.6	41.1	40.2	40.0	39.9	40.2
Papua New Guinea	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Rwanda	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Senegal	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Sudan	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Tajikistan	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Tanzania	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Uganda	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Uzbekistan	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Vietnam	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Yemen	48.0	56.2	73.3	81.6	85.8	90.9	85.8	72.1	64.3	64.8	54.9	44.5	37.1	32.1	27.8
Zambia	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Zimbabwe	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

Source: IMF staff estimates and projections. Projections are based on staff assessments of current policies (see "Fiscal Policy Assumptions" in text).

Note: For country-specific details, see "Data and Conventions" in text and Table D.

[1] Ghana is in the process of restructuring its debt. Government debt projections are based on a pre-debt restructuring scenario.

[2] Debt includes overdrafts from the Central Bank of Nigeria and liabilities of the Asset Management Corporation of Nigeria. The overdrafts and government deposits at the Central Bank of Nigeria almost cancel each other out, and the Asset Management Corporation of Nigeria debt is roughly halved.

Table A23. Advanced Economies: Structural Fiscal Indicators

(Percent of GDP, except when indicated otherwise)

	Pension Spending Change, 2022–30[1,9]	Net Present Value of Pension Spending Change, 2022–50[2,9]	Health Care Spending Change, 2022–30[3a,3b]	Net Present Value of Health Care Spending Change, 2022–50[2]	Gross Financing Need, 2023[4]	Average Term to Maturity, 2023 (years)[5]	Debt to Average Maturity, 2023[6]	Projected Interest Rate–Growth Differential, 2023–28 (percent)	Prepandemic Overall Balance, 2012–19	Projected Overall Balance, 2023–28	Nonresident Holding of General Government Debt, 2022 (percent of total)[7]	Net Financial Worth of General Government, 2021 (percent of GDP)[10]
Average	0.6	17.3	2.3	94.3	20.0	7.3	16.7	–1.4	–3.2	–4.2	29.3	
G7	0.6	16.2	2.6	105.6	24.0	7.0	19.0	–1.3	–3.9	–5.4	27.4	
G20 Advanced	0.6	16.8	2.6	103.0	22.5	7.1	18.2	–1.3	–3.7	–5.1	27.6	
Andorra	2.2	84.2	. . .	. . .	–3.3	7.5	5.0	. . .	2.2	3.5	. . .	. . .
Australia	–0.1	–3.4	1.4	55.8	2.5	6.9	7.6	–0.4	–2.7	–1.6	31.9	–41.2
Austria	1.1	24.7	1.2	53.4	6.3	12.1	6.2	–2.4	–1.2	–1.8	59.3	–55.6
Belgium	1.3	41.1	1.5	68.5	16.3	10.4	10.2	–1.4	–2.4	–5.1	51.3	–90.6
Canada	0.7	15.7	1.1	45.1	9.3	5.9	17.9	–0.5	–0.5	–0.5	19.6	–37.1
Croatia	0.4	1.1	1.1	48.2	7.6	5.4	11.9	–3.4	–2.2	–1.0	41.2	–43.4
Cyprus	0.7	18.5	. . .	. . .	8.1	8.3	9.4	–3.8	–1.4	1.4	81.1	–55.1
Czech Republic	0.4	28.3	0.6	25.4	7.7	2.9	15.6	–2.2	–0.6	–2.2	. . .	–13.1
Denmark	–0.5	–18.8	1.3	47.2	0.7	8.6	3.5	0.3	0.2	0.6	22.0	–18.3
Estonia	–0.5	–19.1	0.5	23.9	. . .	7.2	3.0	–3.5	–0.5	–3.0	95.9	14.2
Finland	0.4	–2.6	1.1	39.2	8.8	7.4	9.9	–1.5	–1.8	–2.1	46.4	–30.6
France	0.5	2.4	1.2	49.4	10.6	8.4	13.2	–1.8	–3.6	–4.0	45.8	–146.7
Germany	0.9	26.7	0.7	38.8	6.5	6.6	10.0	–2.5	0.9	–1.2	38.7	–70.0
Hong Kong SAR	1.2	47.9	. . .	. . .	. . .	. . .	. . .	–1.8	2.5	–0.3	. . .	. . .
Iceland	1.2	46.4	1.2	55.0	4.7	4.5	4.5	0.2	1.1	–0.8	11.3	–35.1
Ireland	0.9	35.2	0.4	21.2	–1.7	10.9	3.9	–3.7	–2.6	1.5	53.0	–40.1
Israel	0.2	12.2	0.3	14.3	. . .	6.9	8.5	–1.7	–2.8	–2.8	17.5	. . .
Italy	1.5	33.5	0.5	27.2	23.0	6.9	20.9	–0.5	–2.5	–3.4	25.9	–226.0
Japan	–0.6	8.0	1.1	39.8	34.1	8.3	30.8	–2.6	–4.7	–3.5	13.9	–161.3
Korea	1.1	50.6	1.8	78.6	3.0	10.4	5.2	–2.4	1.3	–0.4	. . .	–11.7
Latvia	–0.2	–9.9	0.7	29.5	. . .	7.5	5.4	–4.5	–0.7	–1.9	. . .	–20.5
Lithuania	0.6	17.5	1.0	46.6	4.4	8.6	4.2	–3.6	–0.6	–1.2	61.7	–17.2
Luxembourg	1.6	62.3	0.7	35.2	. . .	8.4	3.3	–3.3	1.6	–1.4	45.0	51.1
Malta	–0.5	–4.7	. . .	. . .	10.0	7.8	7.0	–2.6	–0.2	–3.2	15.0	–39.5
The Netherlands	1.0	34.3	1.6	62.7	3.9	9.0	5.5	–2.0	–0.8	–2.2	39.4	–33.3
New Zealand	1.1	35.5	1.3	54.6	4.0	7.2	6.4	0.1	–0.3	–1.8	28.0	. . .
Norway	1.0	25.1	1.4	55.9	. . .	4.5	8.2	–1.1	7.8	12.6	62.6	278.2
Portugal	1.2	20.8	1.0	43.5	4.8	7.3	14.9	–1.8	–3.5	–0.2	45.2	–105.7
Singapore[8]	0.8	30.5	. . .	. . .	5.4	3.3	50.8	. . .	4.6	3.0	. . .	. . .
Slovak Republic	1.1	49.5	0.4	18.9	6.8	8.7	6.6	–3.9	–2.3	–4.5	44.1	–51.9
Slovenia	0.8	59.6	0.7	35.3	4.2	9.7	7.1	–4.2	–3.4	–2.3	48.8	–32.6
Spain	–0.2	4.6	1.2	51.9	7.7	7.9	13.5	–1.9	–5.4	–3.4	39.9	–101.2
Sweden	–0.3	–10.7	0.5	21.7	2.9	5.7	5.7	–2.9	0.0	0.1	14.4	26.6
Switzerland	0.4	13.4	2.0	84.6	1.8	10.8	3.7	–2.1	0.5	0.2	7.9	20.6
United Kingdom	0.2	11.1	1.6	64.6	8.3	14.1	7.4	–1.6	–4.2	–3.8	25.8	–139.7
United States	0.7	16.7	3.8	150.3	29.9	5.9	20.7	–1.0	–5.1	–7.3	26.6	–121.7

Sources: Bloomberg Finance L.P.; Joint External Debt Hub, Quarterly External Debt Statistics; national authorities; and IMF staff estimates and projections.

Note: All economy averages are weighted by nominal GDP converted to US dollars at average market exchange rates in the years indicated and on the basis of data availability.

[1] Pension projections rely on authorities' estimates when these are available. When authorities' estimates are not available, IMF staff projections use the method described in Clements, Eich, and Gupta, *Equitable and Sustainable Pensions: Challenges and Experience* (IMF 2014). These pension spending projections may be different from the previous edition of the *Fiscal Monitor* because of new baseline pension numbers, new authorities' projections, or updated demographic data from the UN World Population Prospects.

[2] For net present value calculations, a discount rate of 1 percent a year in excess of GDP growth is used for each economy.

[3a] IMF staff projections for health care spending are driven by demographics and other factors. The difference between the growth of health care spending and real GDP growth that is not explained by demographics ("excess cost growth") is assumed to start at the economy-specific historical average and converge to the advanced economy historical average by 2050 (0.6 percent).

[3b] These health expenditure projections have been updated to include new available underlying health and economic data as well as technical adjustments to the excess cost growth calculation and the age-expenditure profiles. The projections exclude health expenditure growth during the COVID-19 pandemic in the underlying trend expenditure growth estimate.

[4] "Gross financing need" is defined as the projected overall deficit and maturing government debt in 2023. For most economies, data on maturing debt refer to central government securities. Data are from Bloomberg Finance L.P. and IMF staff projections.

[5] For most economies, the average-term-to-maturity data refer to central government securities and are determined by calculating the maturity across government securities, with their respective amounts serving as weights; the source is Bloomberg Finance L.P.

[6] The debt-to-average-maturity data are calculated by dividing government securities with the average term to maturity to quantify the average annual debt repayment obligation.

[7] Nonresident holding of general government debt data are for the fourth quarter of 2022 or latest available from the Joint External Debt Hub, Quarterly External Debt Statistics, which include marketable and nonmarketable debt. For some economies, tradable instruments in the Joint External Debt Hub are reported at market value. External debt in US dollars is converted to local currency and then taken as a percentage of the 2022 gross general government debt.

[8] Singapore's general government debt is covered by financial assets and is mainly issued to deepen the domestic market, meet the Central Provident Fund's investment needs, provide individuals with a long-term savings option, and facilitate the transfer of official reserves not needed by the central bank to the government.

[9] In the case of all EU members, including Slovakia, pension spending projections reflect the estimates published in the latest available Aging Report. Reforms and changes in methodology or assumptions between Aging Report vintages are not incorporated into the *Fiscal Monitor* annexes.

[10] Net financial worth of general government data are for 2021 or latest available from the Public Sector Balance Sheet (PSBS) Database.

Table A24. Emerging Market and Middle-Income Economies: Structural Fiscal Indicators

(Percent of GDP, except when indicated otherwise)

	Pension Spending Change, 2022–30[1]	Net Present Value of Pension Spending Change, 2022–50[2]	Health Care Spending Change, 2022–30[3a,3b]	Net Present Value of Health Care Spending Change, 2022–50[2]	Gross Financing Need, 2023[4]	Average Term to Maturity, 2023 (years)[5]	Debt to Average Maturity, 2023	Projected Interest Rate–Growth Differential, 2023–28 (percent)	Prepandemic Overall Balance, 2012–19	Projected Overall Balance, 2023–28	Nonresident Holding of General Government Debt, 2022 (percent of total)[6]	Net Financial Worth of General Government, 2021 (percent of GDP)[10]
Average	1.4	70.9	0.6	28.9	12.2	7.7	9.8	–2.9	–3.2	–5.4	12.9	
G20 Emerging	1.4	73.8	0.6	28.9	11.8	7.9	9.6	–2.7	–3.4	–6.2	9.0	
Algeria	3.0	142.2	0.6	29.4	. . .	6.8	8.1	–4.0	–8.4	–9.7	1.0	. . .
Angola	0.1	2.3	0.1	5.9	. . .	6.8	12.5	–6.4	–1.6	0.8	. . .	. . .
Argentina	0.7	46.2	1.0	46.5	16.0	7.1	12.6	. . .	–5.0	. . .	30.1	. . .
Belarus	2.7	96.6	0.7	32.0	. . .	. . .	. . .	–2.6	–0.3	1.1	61.5	. . .
Brazil[7]	0.2	30.4	0.9	41.1	19.1	5.6	15.8	2.8	–5.9	–5.4	10.4	–151.4
Bulgaria	0.0	5.4	0.9	41.5	. . .	7.4	2.8	–3.3	–0.9	–3.0	48.5	–5.3
Chile	1.0	44.1	1.2	55.5	3.6	9.8	3.9	–2.3	–1.6	–0.6	36.0	. . .
China	1.8	95.0	0.7	31.1	. . .	7.4	11.2	–3.6	–2.7	–7.4	3.2	. . .
Colombia	2.0	91.4	1.7	79.9	5.0	10.6	5.2	0.1	–2.4	–2.5	35.3	–52.5
Dominican Republic	0.1	2.5	0.6	27.3	5.4	8.5	7.0	–2.5	–3.2	–2.7	53.6	. . .
Ecuador	0.7	35.4	0.9	41.6	6.5	11.4	4.9	0.9	–6.0	–0.6	72.6	. . .
Egypt	1.1	56.7	0.2	9.0	32.2	3.3	28.3	–6.5	–10.1	–8.9	. . .	. . .
Hungary	–0.1	21.7	1.0	42.7	15.5	5.8	11.9	–2.1	–2.3	–3.0	31.1	–55.9
India	0.7	33.3	0.2	8.9	13.0	10.9	7.5	–3.0	–7.0	–7.9	4.7	. . .
Indonesia	0.1	6.7	0.3	14.9	4.0	8.3	4.7	–1.5	–2.2	–2.1	35.2	–12.9
Iran	1.2	86.5	0.5	23.2	. . .	. . .	. . .	–13.8	–1.7	–6.2	. . .	. . .
Kazakhstan	1.2	33.0	0.3	14.2	. . .	5.5	4.2	–2.6	–0.1	–1.2	25.2	49.5
Kuwait	8.5	629.0	1.3	60.7	10.5	1.2	2.9	4.8	12.9	7.2	. . .	. . .
Lebanon	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	–8.8	. . .	. . .	. . .
Malaysia	1.4	66.3	0.4	16.7	. . .	8.8	7.6	–1.9	–2.7	–4.4	21.9	. . .
Mexico	0.8	44.7	0.6	28.1	12.3	8.2	6.4	2.9	–2.9	–3.3	25.0	–74.0
Morocco	1.3	54.6	0.4	19.3	13.7	6.3	11.0	–1.8	–4.4	–3.8	23.7	. . .
Oman	0.2	16.4	0.6	33.1	8.6	7.1	5.4	5.7	–6.2	4.2	. . .	. . .
Pakistan	0.2	6.3	0.1	5.3	23.7	2.3	33.8	–6.1	–5.9	–6.2	29.5	. . .
Peru	. . .	. . .	0.7	33.4	4.1	13.6	2.5	–1.3	–1.0	–1.0	41.1	–22.2
Philippines	0.2	7.3	0.3	13.1	12.6	6.3	9.1	–4.1	–0.4	–3.6	25.7	. . .
Poland	–0.1	–5.5	0.8	33.8	9.7	4.9	10.3	–3.7	–2.4	–4.7	28.9	–37.5
Qatar	0.3	24.3	0.5	23.8	8.6	8.8	4.7	–0.6	9.0	9.5	8.6	. . .
Romania	2.3	74.1	. . .	. . .	12.8	7.1	7.1	–3.7	–2.6	–5.8	40.4	–31.6
Russian Federation	2.2	72.4	1.0	46.1	4.6	7.5	2.8	–0.1	–0.7	–1.3	10.9	17.3
Saudi Arabia	2.8	161.2	0.8	36.2	11.6	10.1	2.4	2.1	–4.2	0.5	33.5	. . .
South Africa	0.2	11.7	0.7	34.7	15.4	11.2	6.6	2.5	–4.1	–6.6	26.2	1.4
Sri Lanka	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	–5.7	. . .	31.8	. . .
Thailand	3.3	113.7	0.6	26.3	10.0	7.9	7.8	–2.0	–0.2	–2.7	11.3	. . .
Türkiye[8]	0.7	46.9	. . .	. . .	. . .	5.5	. . .	. . .	. . .	. . .	. . .	–18.3
Ukraine	. . .	. . .	. . .	. . .	26.0	6.8	13.0	–8.4	–3.0	–9.6	51.9	–32.1
United Arab Emirates	0.4	42.8	0.5	25.4	. . .	3.4	8.6	–2.0	1.9	3.9	. . .	. . .
Uruguay[9]	0.6	40.5	1.2	55.3	6.5	11.9	5.2	–3.7	–2.3	–2.4	47.9	–52.3
Venezuela	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	–12.5	–5.1	. . .	. . .

Sources: Joint External Debt Hub, Quarterly External Debt Statistics; national authorities; and IMF staff estimates and projections.

Note: All country averages are weighted by nominal GDP converted to US dollars at average market exchange rates in the years indicated and on the basis of data availability.

[1] Pension projections rely on authorities' estimates when these are available. When authorities' estimates are not available, IMF staff projections use the method described in Clements, Eich, and Gupta, *Equitable and Sustainable Pensions: Challenges and Experience* (IMF 2014). These pension spending projections may be different from the previous edition of the *Fiscal Monitor* because of new baseline pension numbers, new authorities' projections, or updated demographic data from the UN World Population Prospects.

[2] For net present value calculations, a discount rate of 1 percent a year in excess of GDP growth is used for each economy.

[3a] IMF staff projections for health care spending are driven by demographics and other factors. The difference between the growth of health care spending and real GDP growth that is not explained by demographics ("excess cost growth") is assumed to be the income group historical average (1.2 percent).

[3b] These health expenditure projections have been updated to include new available underlying health and economic data as well as technical adjustments to the excess cost growth calculation and the age-expenditure profiles. The projections exclude health expenditure growth during the COVID-19 pandemic in the underlying trend expenditure growth estimate.

[4] "Gross financing need" is defined as the projected overall balance and maturing government debt in 2023. Data are from Bloomberg Finance L.P. and IMF staff projections.

[5] Average-term-to-maturity data refer to government securities; the source is Bloomberg Finance L.P.

[6] Nonresident holding of general government debt data are for the fourth quarter of 2022 or latest available from the Joint External Debt Hub, Quarterly External Debt Statistics, which include marketable and nonmarketable debt. For some countries, tradable instruments in the Joint External Debt Hub are reported at market value. External debt in US dollars is converted to local currency and then taken as a percentage of 2022 gross general government debt.

[7] Note that the pension spending projections reported in the first and second column do not include savings from the pension reform approved in October 2019.

[8] The average-term-to-maturity data for Türkiye are in accordance with the published data for central government debt securities as of July 2022.

[9] Data are for the nonfinancial public sector, which includes central government, local government, social security funds, nonfinancial public corporations, and Banco de Seguros del Estado. The coverage of fiscal data was changed from the consolidated public sector to the nonfinancial public sector with the October 2019 submission. With this narrower coverage, the central bank balances are not included in the fiscal data. Historical data were also revised accordingly.

[10] Net financial worth of general government data are for 2021 or latest available from the Public Sector Balance Sheet (PSBS) Database.

Table A25. Low-Income Developing Countries: Structural Fiscal Indicators

(Percent of GDP, except when indicated otherwise)

	Pension Spending Change, 2022–30[1]	Net Present Value of Pension Spending Change, 2022–50[2]	Health Care Spending Change, 2022–30[3a,3b]	Net Present Value of Health Care Spending Change, 2022–50[2]	Average Term to Maturity, 2023 (years)[4]	Debt to Average Maturity, 2023	Projected Interest Rate–Growth Differential, 2023–28 (percent)	Prepandemic Overall Balance, 2012–19	Projected Overall Balance, 2023–28	Nonresident Holding of General Government Debt, 2022 (percent of total)[5]	Net Financial Worth of General Government, 2021 (percent of GDP)[6]
Average	0.5	20.0	0.2	8.3	7.5	9.9	–7.3	–3.3	–3.3	48.5	
Afghanistan	. . .	. . .	. . .	. . .	. . .	. . .	. . .	–0.4	. . .	. . .	. . .
Bangladesh	0.2	12.5	0.1	3.0	4.6	8.6	–6.3	–3.5	–4.7	34.9	. . .
Benin	0.0	1.2	0.1	4.5	7.7	6.9	–4.9	–2.6	–3.3	. . .	. . .
Burkina Faso	0.0	2.2	0.4	16.4	3.2	18.9	–3.0	–3.5	–4.5	43.9	. . .
Cambodia	0.4	14.1	0.3	12.3	. . .	. . .	–7.5	–0.9	–3.1	99.5	. . .
Cameroon	0.0	3.2	0.1	3.3	4.3	9.8	–3.5	–3.7	–0.7	65.8	. . .
Chad	0.0	0.7	0.1	4.7	. . .	. . .	–1.6	–1.3	2.7	. . .	. . .
Congo, Democratic Republic of the	. . .	. . .	0.1	3.3	. . .	. . .	–8.9	0.0	–2.1	. . .	. . .
Congo, Republic of	0.2	8.9	0.2	10.6	. . .	. . .	–1.4	–4.3	3.8	. . .	. . .
Côte d'Ivoire	0.1	6.8	0.1	6.2	. . .	. . .	–3.8	–2.4	–3.5	. . .	. . .
Ethiopia	0.0	1.8	0.1	5.8	. . .	. . .	. . .	–2.3	–2.7	. . .	. . .
Ghana[7]	0.2	8.1	0.3	13.3	7.2	11.9	–10.6	–6.8	–3.5	. . .	. . .
Guinea	0.0	0.0	0.1	5.3	. . .	. . .	–9.0	0.8	–2.4	. . .	. . .
Haiti	. . .	. . .	0.1	2.6	. . .	. . .	–15.3	–1.9	–1.8	. . .	. . .
Honduras	0.3	20.2	0.5	21.3	3.5	13.2	–2.4	–1.7	–1.4	. . .	. . .
Kenya	0.2	12.8	0.3	13.5	8.3	8.5	–3.2	–6.5	–3.9	47.5	. . .
Kyrgyz Republic	4.0	114.3	0.3	13.5	. . .	. . .	–6.6	–3.2	–3.1	78.0	–30.0
Lao P.D.R.	0.1	6.9	0.2	6.9	. . .	. . .	–5.8	–4.2	–3.3	. . .	. . .
Madagascar	0.2	10.8	0.2	7.9	. . .	. . .	–9.0	–2.1	–4.2	47.9	. . .
Malawi	–0.1	0.4	0.2	11.2	2.7	25.7	–5.1	–3.9	–5.8	43.0	. . .
Mali	–0.1	–0.6	0.2	7.6	2.9	17.7	–3.9	–2.7	–3.7	. . .	. . .
Moldova	3.0	67.1	0.7	31.7	. . .	. . .	–6.4	–1.4	–3.9	66.9	–9.5
Mozambique	0.0	4.3	0.3	14.2	3.1	29.0	–10.0	–4.2	–0.6	. . .	. . .
Myanmar	0.2	9.6	. . .	. . .	. . .	. . .	–6.6	–2.8	–4.2	. . .	. . .
Nepal	0.1	9.7	0.2	10.3	. . .	. . .	–6.2	–1.3	–4.2	. . .	. . .
Nicaragua	0.6	38.3	0.7	33.9	0.6	68.2	–5.1	–1.3	0.5	90.9	. . .
Niger	0.0	0.6	0.3	11.6	. . .	. . .	–5.5	–3.8	–3.5	. . .	. . .
Nigeria	0.0	0.8	0.1	3.0	10.1	3.8	–6.7	–3.5	–4.9	. . .	. . .
Papua New Guinea	0.1	4.5	0.2	10.5	. . .	. . .	0.0	–4.1	–2.1	. . .	. . .
Rwanda	0.0	1.3	0.4	17.4	7.1	8.9	–8.5	–2.8	–4.4	75.6	. . .
Senegal	0.0	. . .	0.2	10.7	7.6	10.7	–5.2	–3.7	–3.4	. . .	. . .
Sudan	0.0	1.2	0.2	7.0	. . .	. . .	–43.9	–6.3	–1.9	. . .	. . .
Tajikistan	0.4	13.4	0.3	12.5	. . .	. . .	–6.6	–2.6	–2.5	90.3	. . .
Tanzania	0.0	3.8	0.2	8.4	10.7	4.0	–5.4	–2.6	–2.7	. . .	. . .
Uganda	0.1	3.7	0.1	3.8	. . .	. . .	–4.1	–3.1	–1.9	57.3	–30.6
Uzbekistan	2.3	82.9	0.4	17.1	. . .	. . .	–12.1	1.6	–3.4	61.9	. . .
Vietnam	1.5	64.2	0.3	14.6	10.1	3.3	–6.1	–3.5	–1.9	. . .	. . .
Yemen	0.1	8.8	0.1	2.7	. . .	. . .	–14.4	–6.7	–0.8	. . .	. . .
Zambia	0.2	10.1	0.3	13.7	3.8	25.6	–5.7	–6.8	–3.6	. . .	. . .
Zimbabwe	–0.3	–1.8	0.1	4.4	3.1	30.3	–53.3	–3.5	–2.7	. . .	. . .

Sources: Joint External Debt Hub, Quarterly External Debt Statistics; national authorities; and IMF staff estimates and projections.

Note: All country averages are weighted by nominal GDP converted to US dollars at average market exchange rates in the years indicated and on the basis of data availability.

[1] Pension projections rely on authorities' estimates when these are available. When authorities' estimates are not available, IMF staff projections use the method described in Clements, Eich, and Gupta, *Equitable and Sustainable Pensions: Challenges and Experience* (IMF 2014). These pension spending projections may be different from the previous edition of the *Fiscal Monitor* because of new baseline pension numbers, new authorities' projections, or updated demographic data from the UN World Population Prospects.

[2] For net present value calculations, a discount rate of 1 percent a year in excess of GDP growth is used for each economy.

[3a] IMF staff projections for health care spending are driven by demographics and other factors. The difference between the growth of health care spending and real GDP growth that is not explained by demographics ("excess cost growth") is assumed to be the income group historical average (1.2 percent).

[3b] These health expenditure projections have been updated to include new available underlying health and economic data as well as technical adjustments to the excess cost growth calculation and the age-expenditure profiles. The projections exclude health expenditure growth during the COVID-19 pandemic in the underlying trend expenditure growth estimate.

[4] The average-term-to-maturity data refer to government securities and may not take all the external official debt into account; the source is Bloomberg Finance L.P.

[5] Nonresident holding of general government debt data are for the fourth quarter of 2022 or latest available from the Joint External Debt Hub, Quarterly External Debt Statistics, which include marketable and nonmarketable debt. For some countries, tradable instruments in the Joint External Debt Hub are reported at market value. External debt in US dollars is converted to local currency and then taken as a percentage of 2022 gross general government debt.

[6] Net financial worth of general government data are for 2021 or latest available from the Public Sector Balance Sheet (PSBS) Database.

[7] Ghana is in the process of restructuring its debt. Government debt and interest rate projections are based on a pre-debt restructuring scenario.

IMF EXECUTIVE BOARD DISCUSSION OF THE OUTLOOK, SEPTEMBER 2023

The following remarks were made by the Chair at the conclusion of the Executive Board's discussion of the Fiscal Monitor, Global Financial Stability Report, *and* World Economic Outlook *on September 26, 2023.*

Executive Directors broadly agreed with staff's assessment of the global economic outlook, risks, and policy priorities. They welcomed the continued global economic resilience, particularly of some advanced and emerging market economies, but acknowledged that divergent growth prospects across the world's regions pose a challenge to returning to pre-pandemic output trends. In the case of many emerging market and developing economies (EMDEs), the loss of momentum has reduced prospects for income convergence. Directors recognized that tight monetary policies, necessary to fight inflation, and the withdrawal of fiscal policy support to tackle soaring global debt and support disinflation efforts are also headwinds to growth in the short run. Most Directors agreed that increasing geoeconomic fragmentation is also weighing on the recovery and welcomed the Fund's analysis on the costs of fragmentation. A few Directors emphasized that diversification in supply chains is important to build resilience. More generally, a number of Directors stressed that the Fund's communication on geoeconomic fragmentation should be balanced. Directors generally agreed that ending Russia's war against Ukraine remains the single most impactful action to improve the global outlook.

Directors broadly agreed that risks to the outlook are more balanced relative to April 2023, but remain tilted to the downside. While the acute stress in the banking system seen in March this year has subsided, in part due to swift action in Switzerland and the United States, they broadly noted that financial stability risks remain elevated. In particular, Directors emphasized that persistence in global underlying inflation could warrant higher-for-longer policy rates, which could in turn trigger a correction in financial markets and capital flow volatility. They also considered that commodity prices could see more volatility due to climate and geopolitical shocks. Most Directors noted the risk of a further deterioration in China's property sector and, in this regard, welcomed the recent policy actions taken by the authorities. Directors also highlighted the risk of further debt distress in those EMDEs heavily reliant on external borrowing and generally indicated that the presence of a weak tail of banks in some major economies also poses vulnerabilities. Directors emphasized that should financial conditions tighten abruptly, adverse feedback loops could be triggered and again test the resilience of the global financial system.

Directors noted that global core inflation remains persistent and declining only slowly, and stressed that monetary policy should maintain a restrictive policy stance, tailored to country circumstances, until inflation declines sustainably to target. They called for clear and transparent communication to avoid a de-anchoring of inflation expectations. Directors also indicated that policies aimed at encouraging labor market participation can help ease labor market tightness in many advanced economies, which would support disinflation.

Directors acknowledged that the fast pace of monetary policy tightening adds further pressure on the financial sector, requiring careful monitoring of risks, better risk assessment and strengthened supervision, and closing supervision gaps in the nonbank financial sector. They called for an assessment of how consistently international standards in banking regulation were implemented during recent financial stresses. Noting vulnerabilities in the commercial real estate sector of some countries, Directors called for continued vigilance and close monitoring.

Directors stressed the need to gradually tighten fiscal policies as deficits and debt remain elevated. They considered that, although the primary responsibility for restoring price stability lies with central banks, tightening the fiscal stance can further ease inflation by reducing aggregate demand and reinforcing the overall credibility of disinflation strategies. Directors recommended mobilizing revenues through tax capacity building and achieving efficiency gains in spending to help restore some fiscal space, while safeguarding targeted measures to protect the most vulnerable. They also noted that some countries in debt distress may require preemptive and orderly debt restructuring, underscoring the importance of multilateral cooperation in this regard.

Directors expressed concern over the dimming growth prospects for the medium term. In this context, they emphasized the importance of facilitating investment and of targeted and carefully sequenced supply-side reforms, which can enhance productivity growth despite constrained policy space and help dampen inflationary pressures.

Directors called for accelerating decarbonization efforts, while noting that the policy mix will need to strike a balance between climate goals, fiscal sustainability, and political feasibility. They agreed that relying mostly on spending-based measures will be costly and instead favored a combination of revenue, expenditure, and other financing and structural policies to deliver on climate goals. In this context, most Directors agreed that a policy package containing carbon pricing, complemented with measures to address market failures, catalyze private finance and green investment, and mitigate distributional concerns has higher chances to deliver on climate goals and maintain debt sustainability. Some Directors reiterated, however, that carbon pricing is not an adequate solution in all countries. Directors acknowledged that the green transition will be challenging, particularly for EMDEs with high debt and sizable investment needs; at the same time, delaying the transition will only increase its costs. They generally agreed that incorporating climate change considerations into debt sustainability analyses could improve policy planning, while taking into consideration country-specific characteristics.

Directors underscored that internationally coordinated efforts are indispensable to minimize the cost of decarbonization, especially for low-income countries and small developing states. In this context, they highlighted the important catalytic role that the Resilience and Sustainability Trust could play in attracting green financing and investments. Directors stressed that green industrial policies should avoid distortions to trade and investment flows, in line with the rules of the World Trade Organization (WTO). In this context, a few Directors emphasized that measures such as carbon border adjustment mechanisms should also be WTO-compliant to safeguard international trade. While they considered that, in principle, green and food corridor agreements could help safeguard the energy transition and avert food insecurity, a few Directors underscored the difficulty of implementing these mechanisms. More generally, Directors emphasized that safeguarding the rules-based trading system would be important for global prosperity.

Annex 527

"How the Brady Plan Delivered on Debt Relief: Lessons and Implication", Working Paper, WP/23/258, *International Monetary Fund*, December 2023

INTERNATIONAL MONETARY FUND

How the Brady Plan Delivered on Debt Relief:

Lessons and Implications

Neil Shenai and Marijn A. Bolhuis

WP/23/258

2023
DEC

WORKING PAPER

 WP/23/258

IMF Working Paper
Strategy, Policy & Review

How the Brady Plan Delivered on Debt Relief: Lessons and Implications
Prepared by Neil Shenai and Marijn A. Bolhuis*

Authorized for distribution by Ceyla Pazarbasioglu
December 2023

ABSTRACT: Rising debt vulnerabilities in low- and middle-income countries have rekindled interest in a Brady Plan-style mechanism to facilitate debt restructurings. To inform this debate, this paper analyzes the impact of the original Brady Plan by comparing macroeconomic outcomes of 10 Brady countries to 40 other emerging markets and developing economies. The paper finds that following the first Brady restructuring in 1990, Brady countries experienced substantial declines in public and external debt burdens and a sharp pick-up in output and productivity growth, anchored by a comparatively strong structural reform effort. The impact of the Brady Plan on overall debt burdens was many times greater than initial face value reductions, indicating the existence of a "Brady multiplier." Brady restructurings took longer to complete than non-Brady restructurings. Today, similar mechanisms could be helpful in delivering meaningful debt stock reduction when solvency challenges are acute, but Brady-style mechanisms alone would not solve existing challenges in the sovereign debt landscape, including those related to creditor coordination, domestic barriers to economic reforms, and the increased prevalence of domestic debt, among others.

RECOMMENDED CITATION: Shenai, Neil and Marijn A. Bolhuis (2023), "How the Brady Plan Delivered on Debt Relief: Lessons and Implications." IMF Working Paper 23/258.

JEL Classification Numbers:	F34, F42, H63, H81, G15
Keywords:	Brady Plan; sovereign debt restructuring; debt relief; debt sustainability; differences-in-differences; synthetic control method
Author's E-Mail Address:	nshenai@imf.org, mbolhuis@imf.org

* The authors would like to thank Ceyla Pazarbasioglu for her overall guidance of this project, as well as Anteneh Addisu, Serkan Arslanalp, Tamon Asonuma, Mary Chaves, Emmanuel Comolet, Jesse Corradi, Christopher Dielmann, Mark Flanagan, Sean Hagan, Tara Hariharan, Allison Holland, Henry Hoyle, Federico Sequeda, Mark Sobel, Arthur Sode, Tao Tan, and Tim Willems for their helpful comments. They are also grateful for the many useful conversations on sovereign debt with Sascha Buetzer, David Malpass, and Mark Rosen. Yue Chang and Shiming Xiong provided excellent research assistance.

WORKING PAPERS

How the Brady Plan Delivered on Debt Relief

Lessons and Implications

Prepared by Neil Shenai and Marijn A. Bolhuis

Contents

FIGURES

TABLES

Glossary

AE	-	Advanced economy
DDSRO	-	Debt- and debt-service reduction operation
DiD	-	Difference-in-differences
EM	-	Emerging market
EMDE	-	Emerging markets and developing economy
HIPC	-	Heavily Indebted Poor Country Initiative
IDA	-	International Development Association
IFI	-	International financial institution
IMF	-	International Monetary Fund
LIC	-	Low-income country
MONA	-	Monitoring of Fund Arrangements database
MYRA	-	Multi-year rescheduling agreements
NPC	-	Negative pledge clause
NPV	-	Net-present value
OSI	-	Official sector involvement
PRGT	-	IMF's Poverty Reduction and Growth Trust
PWT	-	Penn World Table
QPC	-	Quantitative performance criteria (IMF programs)
RSBs	-	Recovery and Sustainability Bonds
SCDI	-	State-contingent debt instrument
SCM	-	Synthetic control method
TFP	-	Total factor productivity
UCT	-	Upper-credit tranche

Introduction

In March 1989, U.S. Treasury Secretary Nicholas Brady launched a plan for distressed sovereigns to restructure unsustainable debts via the issuance of so-called "Brady bonds." Under Brady exchanges, creditors accepted face value and net-present value (NPV) haircuts in exchange for greater assurances about debtors' capacity to repay, while debtors used the debt relief provided to restore debt sustainability and growth. Several inducements helped achieve voluntary creditor participation in Brady exchanges, including collateralized interest and principal payments of Brady bonds, debtors' commitments to economic reform under International Monetary Fund (IMF) programs, and the enhanced liquidity of the restructured claims. Overall, the original Brady plan was viewed as a success as it reduced emerging market (EM) debt burdens, restored market access, diversified the EM creditor base, took illiquid loans off of advanced economy (AE) commercial bank balance sheets and converted them into tradeable securities, and safeguarded economic reform momentum (EMTA, 2022).

Some analysts have recently recommended rebooting a Brady-style mechanism. For instance, Lee Buchheit and Adam Lerrick proposed a Brady bond-style exchange structure in which low-income governments restructure the entire stock of their external debt under one of two Brady-like structures (Buchheit & Lerrick, 2023).[1] Brahima S. Coulibaly and Wafa Abedin argued that the World Bank and IMF could manage a Brady-style debt exchange mechanism for heavily indebted countries, which in turn would reduce debt risks (Coulibaly & Abedin, 2023). Ying Qian also claimed that Brady-like restructurings could be useful in reducing post-COVID sovereign debt loads while enhancing the resilience of debt portfolios by introducing, for instance, state-contingent debt instruments (SCDIs) or commodity-linked provisions in the restructured bonds (Qian, 2021).[2] Previously, Nicholas Economides and Roy C. Smith argued that so-called "Trichet Bonds" could be used to resolve the European sovereign debt crisis.[3]

However, these perspectives raise several unanswered questions. Authors such as Buchheit & Lerrick and Coulibaly & Abedin do not spell out how the Brady Plan delivered on debt relief and enabled better macroeconomic outcomes, taking its benefit for debtors as given. They also do not explain the underlying mechanisms by which Brady exchanges can catalyze better outcomes than alternative approaches. Moreover, many advocates for a rebooted Brady Plan do not emphasize the critical role played by structural reforms in enhancing outcomes in Brady restructurers, nor do they explain why a mechanism designed for emerging markets with market access would help address debt issues in low-income countries, whose debt stocks are often held by official creditors. This paper thus contributes to the debate by elucidating the mechanisms by which original Brady restructurers achieved better outcomes in debt restructuring and growth.

Several authors have studied the impact of the Brady Plan previously. For instance, Gumbau-Brisa & Mann (2009) argue that Brady restructurings improved the market for distressed sovereign debt by improving solvency and better aligning prices with fundamentals, rather than short-run factors such as sentiment. Moreover, Brady restructurers also undertook economic reforms before and after restructurings that were seen

[1] One option includes a cash down-payment structure, which would guarantee an up-front payment to the creditor for agreeing to restructure, while the other option had a "floor of support" structure, where a highly rated zero-coupon financial instrument collateralizes the restructured bond. See also (Wolf, 2022) for a summary of the Buchheit-Lerrick plan, as well as Annex II for more details.

[2] SCDIs and other commodity-linked structures were used in Brady restructurings as well.

[3] Under this scheme, the European Central Bank would issue zero-coupon bonds to serve as collateral for restructured sovereign claims of Euro Area members, see (Economides & Smith, 2011).

as growth- and credit-enhancing (EMTA, 2022), including those reforms envisaged, urged, and helped implemented by the World Bank. As argued by Arslanalp & Henry (2005), Brady treatments led to significant stock market appreciations in Brady restructuring countries relative to the control group. The authors also show that Brady restructurings were not a zero-sum game between creditors and debtors: commercial banks with significant developing country loan exposure (i.e., those most exposed to Brady restructurers) experienced a notable rise in their market capitalization relative to a control group of financial institutions.[4]

To add to this discussion, this paper analyzes how the original Brady Plan delivered on debt relief and growth using several empirical methods. [5] In so doing, it contributes to the literature on sovereign debt restructuring. Specifically, this paper estimates the impact of the Brady Plan by comparing macroeconomic outcomes of 10 Brady countries for which data are available to 40 other emerging markets and developing economies (EMDEs) using non-staggered and staggered difference-in-differences and synthetic control approaches. To the authors' knowledge, it is the first attempt of using these three methods to analyze the impact of the Brady Plan.

Results show Brady countries achieved better outcomes than non-Brady peers. Brady restructurers tended to achieve lower public debt, lower external debt, higher growth, and lower inflation relative to the non-Brady control group. The long-term impact of Brady face value reductions on debt levels was multiplied many times over—mainly driven by the more than doubling of the growth rate of Brady countries in the 1990s relative to the 1980s. This pick-up in growth followed largely from total factor productivity growth, which is consistent with the relatively strong structural reform effort in Brady countries.[6]

The rest of this paper proceeds as follows. Section II provides background and context for the original Brady Plan. Section III presents the paper's empirical analysis. Section IV discusses the lessons that follow from this paper's analysis. Section V concludes. Annex I provides additional information on the empirical results of the paper. Annex II summarizes the menu of options for the original Brady Plan and options for a rebooted Brady Plan in the 2020s presented by other authors.

[4] As found by Arslanalp & Henry (2005), when developing countries announced debt relief agreements under the Brady Plan, their stock markets appreciated by an average of 60 percent in real dollar terms—a $42 billion increase in shareholder value. There is no significant stock market increase for a control group of countries that do not sign Brady agreements. The stock market appreciations successfully forecast higher future resource transfers, investment, and growth. Since the market capitalization of U.S. commercial banks with developing country loan exposure also rises—by $13 billion—the results suggest that both borrower and lenders can benefit from debt relief when the borrower suffers from debt overhang.

[5] Hereafter, the terms "Brady Plan" and "Brady restructurings" will be used interchangeably and refer to the suite of economic policy actions taken by debtors, creditors, and IFIs to reduce the face value of existing debt while undertaking complementary and related economic reforms.

[6] These primary results are confirmed via two robustness checks.

Background on the Brady Plan

The 1970s saw a rise in bank lending to EMDEs, mainly in Latin America, with a reversal in the early 1980s that contributed to debt sustainability challenges for many heavily indebted countries. The 1970s oil price shocks caused large balance of payments surpluses in oil-exporting countries, which deposited their foreign exchange earnings in U.S. commercial banks. In turn, banks lent to Latin American sovereigns, with the total stock of outstanding debt rising from about $30 billion in 1970 to $330 billion in 1982. As U.S. interest rates rose and the world economy entered a recession in 1981, many Latin American countries lost market access and could no longer service their debts as commercial banks retrenched their lending (Sims & Romero, 2013).

Latin America's debt troubles were originally treated as a liquidity—rather than a solvency—problem by creditors. During the initial phase of the 1980s Latin American debt crisis, international lenders and IFIs expected that macroeconomic adjustment policies could help these countries restore sustainability and regain market access. Debtors adopted multiyear rescheduling agreements (MYRAs) to continue to service interest payments on existing debt while rescheduling principal payments. The total face value of Latin America's external debt stocks was thus left unchanged during this liquidity-oriented period. However, the lack of growth and new private sector lending indicated that these initial strategies were not working, and that the NPV reduction provided by MYRAs was insufficient to restore sustainability. Thus, United States Treasury Secretary James Baker developed the Baker Plan in 1985, in which long-term structural reforms, rather than short-term macroeconomic adjustment, were emphasized. Baker further called on commercial banks and IFIs to lend $30 billion in fresh capital to the 15 countries eligible for the Baker Plan.[7] Again, debt stock reduction was not supported (Sturzenegger & Zettelmeyer, 2006), (Truman, 2020).

By the late 1980s, it was clear that face value reduction was needed to restore debt sustainability. During the initial phase of the Latin American debt crisis, there was a worry that defaults would lead to capitalization problems for the region's lenders. Initial debt restructurings and IFI assistance, coupled with adjustment programs, helped distressed sovereigns service their debts and gave time for lenders to rebuild buffers. By end-1988, major commercial banks reduced their exposure to Latin America's troubled sovereigns by nearly 50 percent. Moreover, as more banks recognized the reduced market value of their claims on distressed sovereigns, they were more inclined to provide debt relief. Many debtors also made efforts to retire their external debt as well. Together, systemic stability concerns had declined by the late 1980s, though the region was constrained by low growth, limited new lending, and unsustainable debt loads. These factors opened the door to a more fulsome debt relief process (Clark, 1994).

U.S. Treasury Secretary Nicholas Brady announced a plan for reducing the debts of heavily indebted emerging markets in March 1989. The plan proposed to offer debt relief in the form of, among others, face value reductions, face value preservation but lower coupon payments and a maturity extension, or creditors putting in new money via voluntary exchanges (see Annex II). The new debt would have reduced interest and principal payments while including credit enhancements to encourage creditor participation in the restructuring process. Credit enhancements included the use of IFI funds to purchase and provide collateral for restructured bonds, usually in the form of zero-coupon U.S. Treasury securities, as well as macroeconomic stabilization and

[7] The list of countries in the Baker plan included Argentina, Bolivia, Brazil, Chile, Colombia, Cote d'Ivoire, Ecuador, Mexico, Morocco, Nigeria, Peru, the Philippines, Uruguay, Venezuela, and Yugoslavia. These countries were selected as they were the ones for which commercial banks had large exposures, see Clark (1994).

reform programs anchored by IMF programs and World Bank engagement to strengthen debtors' capacity to repay creditors.[8] The IMF's Executive Board also introduced its lending into arrears policy to allow debtors to run temporary arrears to creditors provided debtors were negotiating debt relief in good faith. This policy positively impacted Brady deals since it mitigated delays to restructurings and to IMF support.[9] Further, commercial banks were urged to waive negative pledge clauses (NPCs)—or conditions that prohibit issuing new collateralized debt unless incumbent debt holders are given equivalent amounts of collateral—on the old debt. The aim of these policies was to restore debt sustainability, provide a credible plan for macroeconomic reform via IMF programs, and employ sufficient carrots and sticks to urge participation in debt treatments (Clark, 1994), (Sturzenegger & Zettelmeyer, 2006), (Truman, 2020).

Seventeen countries undertook Brady restructurings beginning in 1990 through 1998 (Table 1). The first Brady restructuring took place in February 1990 with Mexico, which ultimately restructured about $54 billion of debt (worth about 19 percent of Mexico's 1990 GDP) and included a 13 percent face value reduction. The average face value reduction of all Brady restructurers was about 22 percent of GDP worth of restructured debt (Asonuma & Trebesch, 2016). Many of the early Brady restructurers, including Mexico, Nigeria, and Venezuela were oil exporters originally targeted for structural adjustment under the preceding Baker Plan (Bogdanowicz-Bindert, 1986). Debt restructurings under the Brady Plan tended to take longer than other restructurings, with an average time to settlement of about 6 years, which is longer than the average duration of debt restructurings from 1978-2020 (about 3 years, see (Asonuma & Trebesch, 2016)).

Brady exchanges had several features. Restructurings were done on a case-by-case basis. Debtors and creditors negotiated debt relief packages among a menu of options that was tailored to each restructuring request. The primary two options pursued via Brady exchanges were par bond exchanges and discount bond exchanges. Both restructuring options included an upfront cash payment, usually between 7 to 13 percent of the principal and interest payments of the original debt, while the remaining new obligations were securitized and restructured according to the respective exchange's features. In par bonds exchanges, the face value of the new bonds would be the same as the old bonds, while the new bonds would have lower fixed interest rate payments. Discount bonds involved face value reductions of about 30-35 percent, with variable interest rate structures (EMTA, 2022) (see Annex II). Relative to Non-Brady debt restructurings that involved commercial creditors, Brady exchanges were more likely to include new money, affect principal coming due, and include larger haircuts (see Figure 1, panel B).

Brady bonds had credit and liquidity enhancements. Their principal payments were collateralized by zero-coupon U.S. Treasury securities, while interest payments were secured by high-grade investment securities purchased with IMF program augmentation and set asides that were earmarked for these debt operations. These zero-coupon structures were particularly appealing in the context of the 1980s and 1990s interest rate environment, where zero-coupon securities could be purchased at a deep discount relative to regular coupon-bearing structures given the former's higher duration (or interest rate sensitivity). Rolling interest rate guarantees—enabled by IFI lending and additional bilateral new money held in a trust at the Federal Reserve—

[8] Under Brady restructurings, debtors would receive debt relief in exchange for undertaking economic reforms anchored by IMF programs. Reforms generally focused on lowering inflation, current and capital account liberalization (including reducing trade barriers), and structural reforms. See (Cline, 1995) for a summary. Recent research suggests that when countries are in debt distress, fiscal consolidation and debt relief combined produce the best outcomes for reducing long-term debt ratios. Often, such consolidations can be targeted via IMF-supported programs with UCT-quality conditionality. See (IMF, 2023)..

[9] The debt- and debt-service reduction operation (DDSRO) policy was part of a broader set of IMF policy reforms in 1989, adopted in the context of the Brady Plan, aimed at resolving the EM debt crisis by facilitating market-based restructurings. Under the policy, the Fund provided financial support to DDSROs on 11 occasions between 1989 and 1998 (see IMF (2021)).

also alleviated near-term default concerns. These *credit enhancements* helped induce private sector involvement in Brady restructurings. Brady bonds also had *liquidity enhancements* as commercial creditors were able to turn their claims into tradable financial securities. Indeed, one of the benefits of the Brady Plan was to offer the opportunity to bilateral creditors to turn illiquid loans into tradable securities, thereby strengthening the liquidity of restructured claims while reducing creditor concentration (Miles, 1999).[10] Brady bonds helped open new categories of institutional investors that were attracted to the relatively higher returns offered by Brady bonds while taking advantage of still seeking the safety provided by their collateralized structure. This potential benefit is further evidenced by the fact that external sovereign bonds generally offer excess returns over compensation for the risk of default, while the same may not necessarily be true for bilateral claims (Meyer, Reinhart, & Trebesch, 2022).

Brady countries undertook economic reforms. These reforms included measures in UCT-quality IMF programs and structural reforms encouraged by the World Bank. These programs served two purposes: they enhanced the capacity to repay restructured claims while signaling debtors' commitment to reform and sound public finances. Brady Plan era reforms often followed several years' worth of macroeconomic adjustment programs undertaken during the MYRA and Baker Plan eras.

The Brady Plan had strong ownership by the United States. In the 1980s, the United States in close collaboration with Japan underwrote the Brady Plan by providing enhancements for interest and principal payments on the restructured bonds. The United States government used its influence at the IFIs, as well as its connections to its commercial creditors, to urge debt relief via Brady exchanges. The United States took a leadership role in helping to address the challenges of engaging multiple stakeholders in debt restructuring, including by helping restructurers navigate the stigma and operational opacity associated with debt restructuring. Additionally, the United States provided leadership to the IFIs to build a consensus to support implementation of the plan.[11]

[10] Of course, creditors may need to overcome domestic legal constraints that would hamper their willingness to convert existing bilateral loans into tradable bonds, such as obtaining parliamentary approval.

[11] The United States paved the way to debt relief by urging its commercial creditors to waive NPCs, for instance, when engaging in Brady exchanges. For more on the U.S. role in the Brady Plan, see (Clark, 1994).

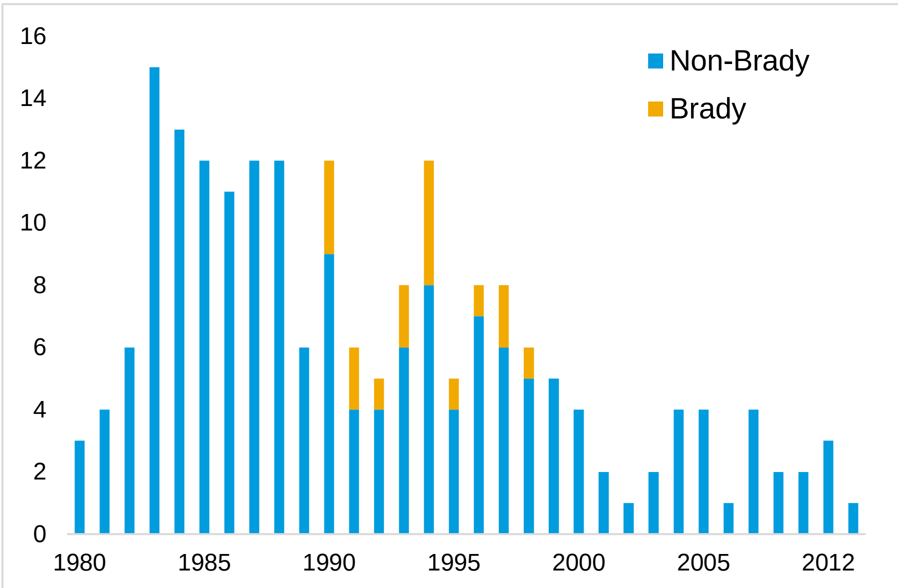
Table 1: Brady Restructurings

Brady country	Date of restructuring (MM / YYYY)	Debt restructured (USD millions)	Debt restructured (% of GDP)	Face value reduction	Time to settlement (months)
Mexico	02 / 1990	54,300	18.7	13.1%	14
Costa Rica	05 / 1990	1,384	24.1	47.0%	49
Venezuela	12 / 1990	19,585	40.5	6.8%	23
Uruguay	01 / 1991	1,610	12.0	16.4%	19
Nigeria	12 / 1991	5,883	9.8	34.6%	31
Philippines	12 / 1992	4,471	7.4	13.2%	29
Argentina	04 / 1993	28,476	10.8	9.5%	64
Jordan	12 / 1993	1,289	23.0	28.7%	60
Brazil	04 / 1994	43,257	7.9	9.1%	59
Bulgaria	06 / 1994	7,910	81.4	31.1%	53
Dom. Rep.	08 / 1994	1,087	7.4	39.7%	88
Poland	10 / 1994	13,531	13.0	31.9%	62
Ecuador	02 / 1995	7,170	31.2	16.4%	104
Panama	04 / 1996	3,936	39.2	0.7%	90
Peru	03 / 1997	10,600	18.8	34.2%	155
Vietnam	12 / 1997	782	2.3	26.1%	194
Cote d'Ivoire	03 / 1998	6,462	37.1	60.2%	180

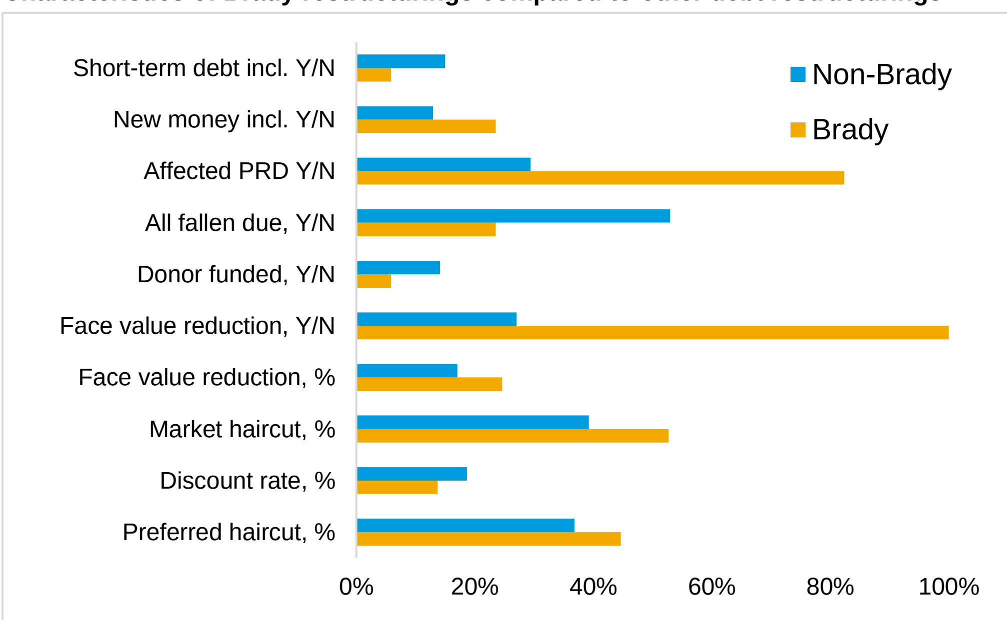
Notes: (Asonuma & Trebesch, 2016)**,** (Cruces & Trebesch, 2014), and authors' calculations. GDP data from World Economic Outlook. Note that Russia also had a Brady-like restructuring in 1998 but was not an original Brady Plan country.

Figure 1. Brady Restructurings in Historical Context (1980-2013)

(A) Number of debt restructurings per year



(B) Characteristics of Brady restructurings compared to other debt restructurings



Notes: (Asonuma & Trebesch, 2016), (Cruses & Trebesch, 2014), and authors' calculations. Dataset includes defaults on commercial creditors and does not include Paris Club treatments.

Analyzing the Impact of the Brady Plan

To analyze the macroeconomic impact of the original Brady Plan, this paper studies the impact of the Brady restructurings using a sample of 50 EMDEs. To distinguish the effect of debt relief from that of common shocks, the change in macroeconomic outcomes for Brady countries with a similar group of EMDEs that did not receive debt relief under the Brady Plan are compared. This paper's research design addresses the non-random nature of achieving debt relief treatment by using difference-in-differences (DiD) and synthetic control methods to compare the outcomes of Brady restructurings with otherwise observationally similar countries.[12] This section details the empirical strategy and presents the results of the paper.

Table 2: Variables and Data Sources[13]

Variable	Source(s)
Gross government debt	Global Debt Database (Mbaye, Moreno Badia, & Chae, 2018), Historical Public Debt Database, World Economic Outlook
External debt	World Bank Development Indicators
Real GDP	Penn World Table 10.0 (Feenstra, Inklaar, & Timmer, 2015)
GDP deflator	World Economic Outlook and World Bank Development Indicators
Trade openness	Penn World Table 10.0 (Feenstra, Inklaar, & Timmer, 2015)
FDI stock, external liabilities	External Wealth of Nations (Lane & Milesi-Ferretti, 2018)
Physical capital stock	Penn World Table 10.0 (Feenstra, Inklaar, & Timmer, 2015)
Human capital index	
Employment	
Population	
Labor income share	

Sample and sources

The sample for this paper's empirical analysis includes 10 Brady countries for which data could be obtained. These countries included Argentina, Brazil, Costa Rica, Dominican Republic, Ecuador, Jordan, Mexico, Nigeria, Peru, and the Philippines.[14] Data sources are presented in Table 2. The control group consists of 17 countries that received debt restructuring between 1970 and 2013 but did not sign Brady deals and 23 other EMDEs that did not seek debt treatments (see Table 2). Summary statistics of the main macroeconomic variables under consideration are reported in Table 4.

[12] Recent applications of synthetic control methods include studies on the macroeconomic impacts of economic liberalization episodes (Nannicini & Billmeier, 2011) and (Billmeier & Nannicini, 2013); structural and tax reforms (Newiak & Willems, 2017), (Adhikari, Duval, Hu, & Loungani, 2016), and (Adhikari & Alm, 2016); the recent Debt Service Suspension Initiative (Lang, Mihalyi, & Presbitero); IMF precautionary lending programs and rescue loans (Essers & Ide, 2019) and (Kuruc, 2022), respectively; and Brexit (Born, Müller, Schularick, & Sedlacek, 2019).

[13] Any potential biases or omissions in data sources could impact the paper's results. The use of multiple methods and robustness checks helps reduce, but not eliminate, the risks associated with issues from data coverage.

[14] The sample does not include Brady cases of Bulgaria, Cote d'Ivoire, Panama, Poland, Uruguay, Venezuela, and Vietnam due to incomplete data. Note that Russia had a Brady-like deal in 1998 but was not an original Brady Plan nor Baker Plan country, and hence was omitted from this paper's analysis.

Table 3: Sample of Countries

Brady (10)	Non-Brady Restructurings (17)	Non-Brady non-Restructurings (23)
Argentina*	Bolivia	Bangladesh
Brazil	Cameroon	Benin
Costa Rica	Congo, Rep.	Botswana
Dominican Republic	Gabon	Burundi
Ecuador*	Honduras	Colombia
Jordan*	Jamaica	Egypt, Arab Rep.
Mexico	Kenya	El Salvador
Nigeria*	Madagascar	Eswatini
Peru	Malawi	Fiji
Philippines	Morocco	Ghana
	Niger	Guatemala
	Pakistan	Haiti
	Paraguay	India
	Senegal	Indonesia
	Sierra Leone	Iran, Islamic Rep.
	Togo	Lesotho
	Türkiye	Mali
		Mauritius
		Myanmar
		Nepal
		Sri Lanka
		Thailand
		Tunisia

Notes: Table lists EMDEs included in the full sample for the differences-in-differences analysis. The sample excludes Brady cases Bulgaria, Cote d'Ivoire, Poland, Uruguay, Venezuela, and Vietnam due to incomplete data. * denotes oil exporter

Table 2: Selected Summary Statistics

Variable		Brady	Non-Brady Restructurings	Non-Brady Non-Restructurings
Gross government debt, % of GDP, 1989	Mean	70.7	71.1	56.7
	Median	58.9	53.9	48.8
Gross government debt, % of GDP, 1999	Mean	55.4	73.9	54.6
	Median	48.3	63.4	44.3
External debt, % of GDP, 1989	Mean	77.9	81.1	60.8
	Median	75.2	80.0	43.2
External debt, % of GDP, 1999	Mean	54.9	89.5	52.7
	Median	51.3	68.3	40.4
Real GDP growth, %, 1985-1989 av.	Mean	2.8	2.7	4.5
	Median	2.4	3.1	4.6
Real GDP growth, %, 1990-1999 av.	Mean	3.4	1.9	4.6
	Median	3.4	2.3	4.8
Inflation %, 1985-1989 av.	Mean	220	163	11.0
	Median	21.2	6.1	10.0
Inflation %, 1990-1999 av.	Mean	186	18.3	12.7
	Median	21.7	10.0	10.2
Trade openness, 1989	Mean	21.5	28.5	25.2
	Median	17.2	18.1	15.3
Trade openness, 1999	Mean	39.7	34.9	31.5
	Median	36.8	20.4	20.4
FDI stock, share of external liabilities, 1989	Mean	12.3	10.7	18.9
	Median	10.3	8.6	13.4
FDI stock, share of external liabilities, 1999	Mean	26.1	15.8	24.5
	Median	27.6	14.1	20.3
Current account, % of GDP, 1985-1989 av.	Mean	-2.4	-5.2	-.3
	Median	-2.0	-4.6	-2.2
Current account, % of GDP, 1990-1999 av.	Mean	-2.9	-5.0	-3.1
	Median	-2.8	-4.6	-2.3
Net investment income, % of GDP, 1985-1989	Mean	-5.2	-4.7	-3.0
	Median	-4.9	-3.9	-2.3
Net investment income, % of GDP, 1985-1989	Mean	-3.5	-4.8	-1.6
	Median	-3.7	-3.1	-1.5

Methodology

A differences-in-differences (DiD) regression was run to assess the impact of Brady restructurings on various variables of interest (see Table 3).[15] The proposed specification is described below in equation (1):

$$(\mathbf{1})\ y_{it} = \beta \cdot brady_i \times post_t + \gamma_i + \gamma_t + \epsilon_{it} \quad ,$$

where $post_t$ is a dummy equal to one in 1999, and equal to zero in 1989. $brady_i$ is a dummy equal to one for Brady countries. γ_i and γ_t are country- and year-specific fixed effects. Coefficient β thus captures the impact of the Brady restructuring—i.e., it captures the difference in the outcome variable y_{it} for Brady countries relative to the pre-Brady period and non-Brady countries. Note that both average treatments (with an event study at 1989) and a staggered treatment (to accommodate the timing of when Brady restructurings took place in each treated country) are used. Results of these (DiD) regressions are presented in Tables 6 and 7.

As an additional robustness check, a synthetic control method was also used. The SCM provides a useful analytical tool to assess the impact of treatment (in this case, a Brady restructuring) on a country relative to a *synthetic control*, or a combination of comparator countries.[16] This study is interested in the effect α_{it} of the Brady Plan on macro outcome y_{it} in country *i* at time $t \geq t_0$, where t_0 is the time period when the Brady Plan starts to impact the outcome. This effect can be stated as per equation (2):

$$(\mathbf{2})\ \alpha_{it} = y_{it}^{I} - y_{it}^{N},$$

where y_{it}^{I} is the value of y_{it} when the Brady Plan takes place, and y_{it}^{N} is the value of y_{it} in the absence of the Brady Plan. y_{it}^{I} is observed, whereas y_{it}^{N} is not. The SCM estimates a counterfactual (i.e., the synthetic control) for y_{it}^{N} using a weighted average of the observations from the control group (the comparator pool) such that:

$$(\mathbf{3})\ \hat{y}_{it}^{N} = \sum_{n \neq i} w_n y_{nt} \ ,$$

where the weights w_n are constructed such that the synthetic control matches pre-treatment characteristics of the treated country as closely as possible. Specifically, the vector of weights solves the following equations (4):

$$(\mathbf{4})\ \min_{W} ||X_1 - X_0 W||_V = \sqrt{(X_1 - X_0 W)' V (X_1 - X_0 W)}$$

$$subject\ to\ \ w_n \geq 0\ \forall n \neq i$$

$$\sum_{n \neq i} w_n = 1$$

where V is a symmetric and positive semi-definite matrix that weighs the importance of pre-treatment characteristics, constructed to minimize the mean-squared prediction error for the level of the outcome variable (e.g. external debt to GDP) in the pre-treatment periods (1981-1989). As an example, Table 5 includes the

[15] For a background on the DiD approach, see (Baker, Larcker, & Wang, 2021)

[16] (Abadie & Gardeazabal, 2003) developed the SCM, which was subsequently extended by (Abadie, Diamond, & Hainmueller, 2010). For more detailed discussions of the SCM in a macro context, see (Newiak & Willems, 2017) and (Kuruc, 2022).

weights of the synthetic controls for gross public debt. After obtaining the weights, the treatment effect of the Brady Plan at time *t* is constructed as per equation (5):

$$(\mathbf{5})\ \hat{\alpha}_{it} = y_{it}^{I} - \hat{y}_{it}^{N}\ .$$

To assess the macroeconomic impact of the Brady Plan, decompositions of growth and debt dynamics are calculated. For real GDP growth, Cobb-Douglas production functions of real GDP with physical capital and effective labor as inputs is specified as per equation. The growth of real GDP can be decomposed in first differences as per equation (6):

$$(\mathbf{6})\ \Delta \ln Y_t = \Delta \ln TFP_t + \frac{\alpha}{1-\alpha} \Delta \ln k_t + \Delta \ln h_t + \Delta \ln(\frac{L_t}{P_t}) + \Delta \ln P_t\ ,$$

where Y_t is real GDP, TFP_t is total factor factor productivity, k_t is capital per unit of output, h_t is a country's human capital index, $\frac{L_t}{P_t}$ is the employment to population ratio, and P_t is population. α is the capital share, which is measured as one minus the labor share in Penn World Table 10.0.

The change in debt-to-GDP ratio can be decomposed into the contributions from debt relief, economic growth, and a residual. This change is decomposed as per equation (7):

$$(\mathbf{7})\ d_t - d_{t-1} = -relief_t - \frac{g_t}{1+g_t} d_{t-1} + o_t$$

Where d_t is gross government debt to GDP, $relief_t$ is debt relief to GDP, g_t is the growth rate of real GDP, and o_t is the residual that captures the primary balance, exchange rate and inflation effects, and stock-flow adjustments. To assess the contribution of higher output growth of Brady countries to changes in the debt to GDP ratio, the exercise iterates forward from 1989 using a counterfactual growth rate that is 2 percentage points lower than the observed growth rate. Note that two percentage points is about the magnitude of the uptick in trend growth of Brady countries in 1990-1999 relative to 1980-1989 (Figure 3).

Table 3: Country Weights of Synthetic Controls for Gross Public Debt

Brady	Argentina	Brazil	Costa Rica	Dominican Republic	Ecuador	Jordan	Mexico	Nigeria	Peru	Philippines
Control										
Bangladesh	0	0	0	0	0.547	0	0	0.281	0	0
Benin	0.518	0	0	0	0	0	0	0	0.274	0
Bolivia	0	0	0	0	0	0	0	0	0	0
Botswana	0	0	0	0	0	0	0	0	0.141	0
Burundi	0	0	0.624	0	0	0	0	0	0.519	0
Cameroon	0	0	0.335	0	0	0	0	0	0	0
Colombia	0.053	0	0	0	0	0.121	0	0	0	0
Congo, Rep.	0	0	0	0	0	0	0	0	0	0
Egypt, Arab Rep.	0	0	0.042	0	0	0	0	0	0	0
El Salvador	0	0	0	0	0	0	0	0	0	0
Eswatini	0	0.161	0	0	0	0	0.134	0.154	0	0
Fiji	0	0	0	0	0	0	0	0.362	0	0
Gabon	0	0	0	0	0	0	0	0	0.009	0
Ghana	0	0	0	0	0	0	0	0	0.058	0
Guatemala	0.266	0	0	0	0.009	0	0	0.204	0	0
Haiti	0	0	0	0	0	0	0.006	0	0	0.418
Honduras	0	0	0	0	0	0	0	0	0	0
India	0	0.048	0	0	0	0	0.236	0	0	0
Indonesia	0	0.196	0	0	0	0	0	0	0	0
Iran, Islamic Rep.	0	0	0	0	0	0	0	0	0	0
Jamaica	0	0	0	0	0	0	0	0	0	0
Kenya	0	0	0	0.005	0	0	0	0	0	0
Lesotho	0	0	0	0	0	0	0	0	0	0
Madagascar	0	0	0	0.363	0.091	0	0	0	0	0.198
Malawi	0	0	0	0	0	0	0	0	0	0
Mali	0.13	0	0	0	0.352	0.879	0	0	0	0
Mauritius	0	0	0	0	0	0	0	0	0	0
Morocco	0	0	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0	0	0
Nepal	0	0	0	0	0	0	0	0	0	0
Niger	0	0	0	0	0	0	0	0	0	0
Pakistan	0	0	0	0.632	0	0	0	0	0	0
Paraguay	0	0	0	0	0	0	0	0	0	0
Senegal	0	0	0	0	0	0	0.086	0	0	0.006
Sierra Leone	0.032	0	0	0	0	0	0	0	0	0.238
Sri Lanka	0	0	0	0	0	0	0.485	0	0	0
Thailand	0	0	0	0	0	0	0	0	0	0
Togo	0	0.595	0	0	0	0	0.051	0	0	0.14
Tunisia	0	0	0	0	0	0	0	0	0	0
Turkiye	0	0	0	0	0	0	0	0	0	0

Source: Authors' calculations

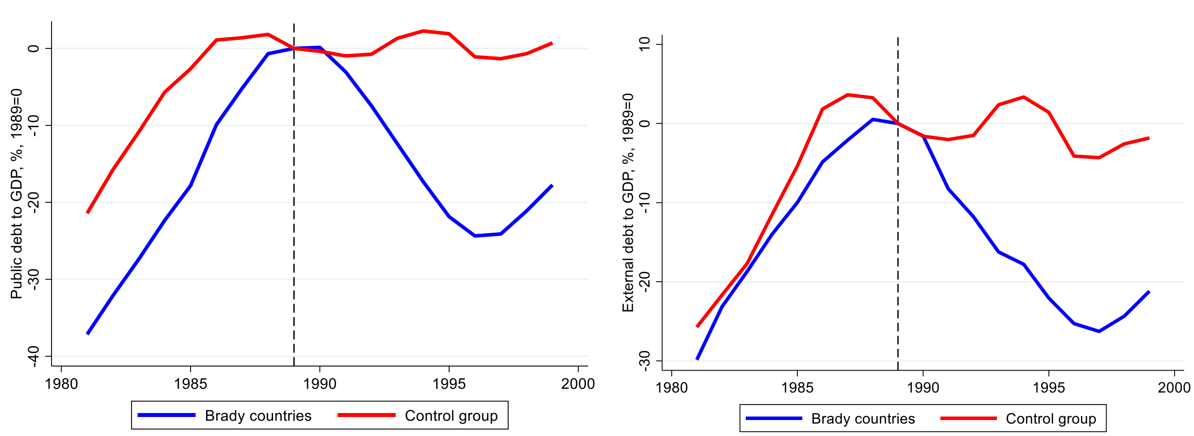
Results

In the decade following the first Brady deal, public debt levels of Brady countries dropped by 20 percentage points of GDP relative to non-Brady countries. Public debt levels of Brady countries grew faster than those of the control group in the decade before 1990 (Figure 2, panel A). After the first Brady deal, debt levels of Brady countries declined by about 25 percentage points of GDP, albeit from a much higher level, while debt levels of the control group flatlined. Similarly, average external debt burdens of Brady countries, which grew at similar rates to non-Brady countries before 1990, fell by roughly 25 percentage points relative to the control group in the following decade (Figure 2, panel B). These findings suggest the Brady Plan had the first-order effect of bringing down debt burdens and thereby enhancing debt sustainability, in line with its goals. Tables 6 and 7 in Annex I summarize the results of the DiD regressions.[17]

Figure 2. Evolution of Public and External Debt Following the First Brady Deal (1980-1999)[1]

(A) Public debt, % of GDP (3y average, deviation from 1989)

(B) External debt, % of GDP (3y average, deviation from 1989)



[1] Public and external debt (as percent of GDP) from 1980 to 1999 in sample of 11 Brady countries and 53 EMDEs that serve as the control group. Lines show group averages by year relative to 1989, the year before the first Brady restructuring. See Annex I for data details.

Brady countries experienced a return of economic growth to trend after their restructurings. In the decade prior to the first debt relief, real GDP of Brady countries grew at an average rate of 1.5 percent per year, whereas non-Brady countries grew at an average rate of more than 3 percent. During the decade following the first Brady deal in 1990, the growth rate of Brady countries more than doubled to 3.4 percent. Economic growth in the control group was unchanged relative to its pre-1990 growth path (Figure 3, Panel A). In 1999, output of Brady countries was 26 percent higher relative to their pre-restructuring trend.

Following debt relief, inflation rates of Brady countries declined significantly relative to the control group. Inflation was high in Brady countries before the restructurings (Figure 3, panel B). The mean of the

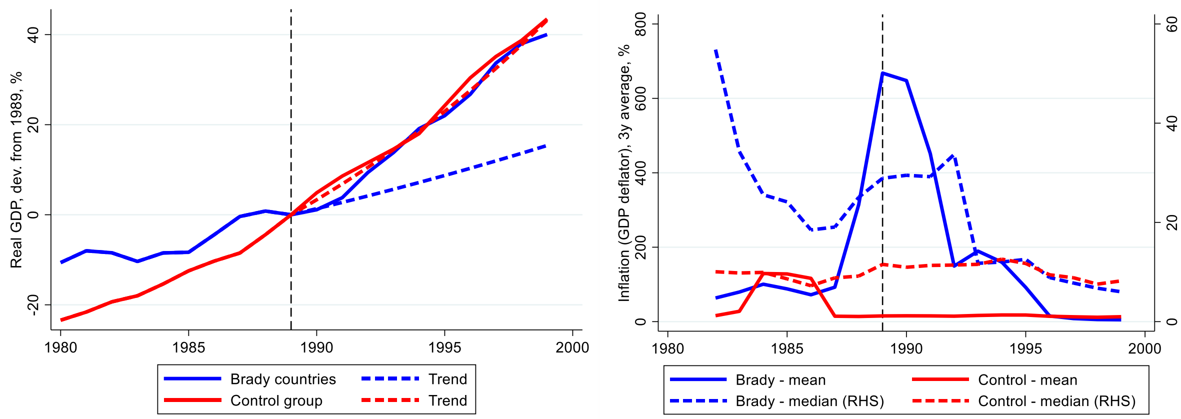
[17] In conducting this analysis, the contribution of changes in fiscal stances to overall debt burden reductions was considered but not pursued due to the lack of granular fiscal data on Brady countries in the 1980s and early 1990s.

annual growth rate of Brady countries' output deflator peaked at a mean of 600 in 1989, and the median peaked at 30 percent in 1992. Yet by 1999, both mean and median inflation rates of the Brady group had fallen below the control group.

Figure 3. Evolution of Output and Inflation Following the First Brady Deal (1980-1999)[1]

(A) Real GDP
(% deviation from 1989)

(B) Inflation
(3y average of GDP deflator growth, %)



[1]Real GDP from 1980 to 1999 in sample of 11 Brady countries and 53 EMDEs that serve as the control group. Lines show group averages by year relative to 1989, the year before the first Brady restructuring. Dashed lines plot group trend growth between 1980 and 1989. Panel B also plots group medians because means are impacted by hyperinflationary episodes, like Brazil. See Annex I for data details.

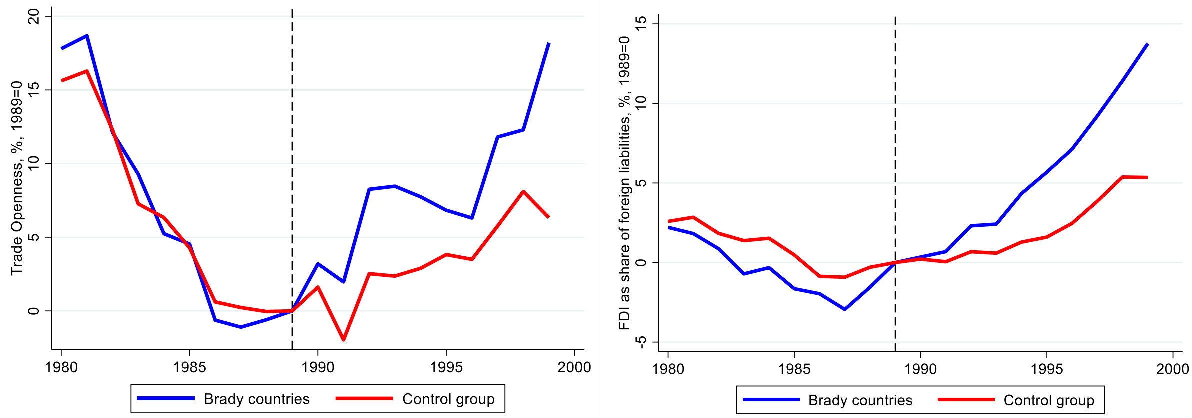
The faster growth of Brady countries was achieved through greater integration into global trade and direct investment. Trade openness of EMDEs declined in the 1980s, falling from 40 percent of GDP to less than 25 percent in 1989. Following the first Brady restructuring, openness of Brady countries increased back to 40 percent in 1990, 10 percentage points above the control group (Figure 4, Panel A). Brady countries also achieved greater exposure to foreign technologies by shifting a larger share of external liabilities into foreign direct investment (FDI). Between 1989 and 1999, the share of FDI in external liabilities increased by 13 percentage points, more than double the increase relative to the control group (Figure 4, Panel B).

By reducing external debt service, Brady deals increased the net resource inflow into Brady countries, providing space for the imports of growth-enhancing investment goods. In the 1980s, current account deficits narrowed in EMDEs, as external inflows dried up and external debt service increased (Figure 5, Panel A). After the first Brady restructuring, the path of current accounts did not diverge between Brady countries and the control group. But net investment income went up substantially in Brady countries, increasing by close to 3 percentage points of GDP in 1997 relative to 1989 (Figure 5, Panel B).

Figure 4. Evolution of Trade and FDI Following the First Brady Deal (1980-1999)[1]

(A) Trade Openness (% deviation from 1989)

(B) FDI Stock (share of external liabilities) (% deviation from 1989)



[1] Trade openness is sum of imports and exports as percentage of GDP. FDI stock is stock of foreign direct investment as share of all external liabilities, expressed as percentage. Lines show group averages by year relative to 1989, the year before the first Brady restructuring. See Annex I for data details.

Figure 5. Evolution of Current Accounts Following the First Brady Deal (1980-1999)

(A) Current Account, % of GDP (% deviation from 1989)

(B) Net Investment Income, % of GDP (% deviation from 1989)

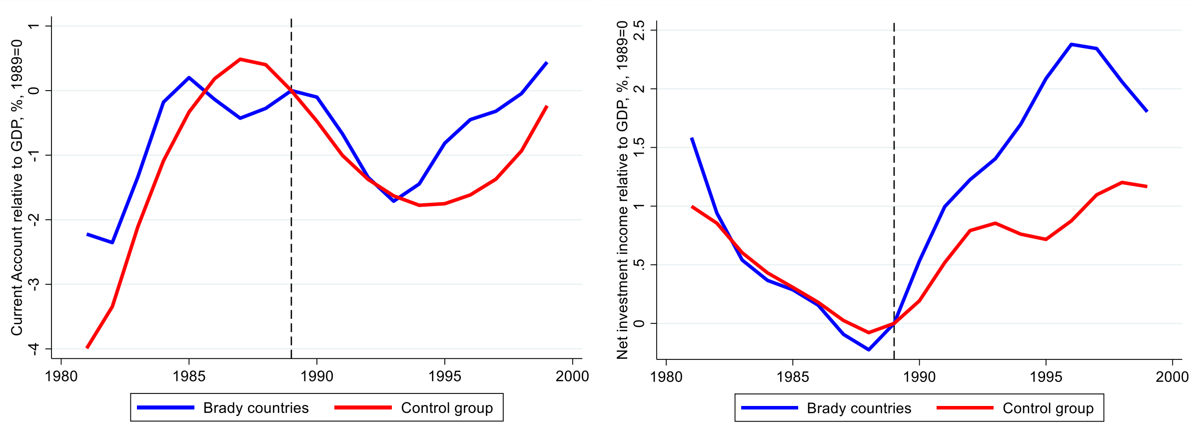
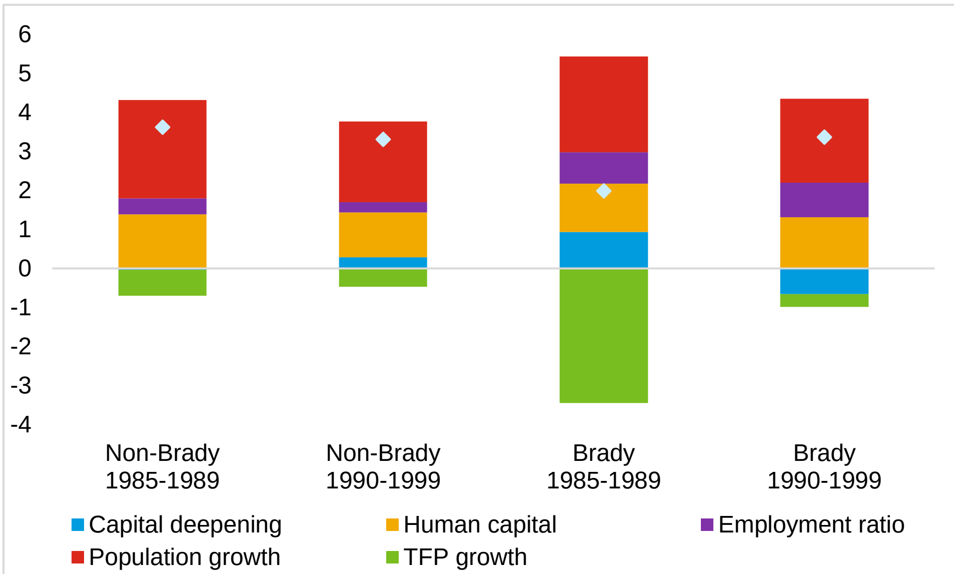


Figure 6. Drivers of Output and Public Debt Growth Following First Brady Deal[1]

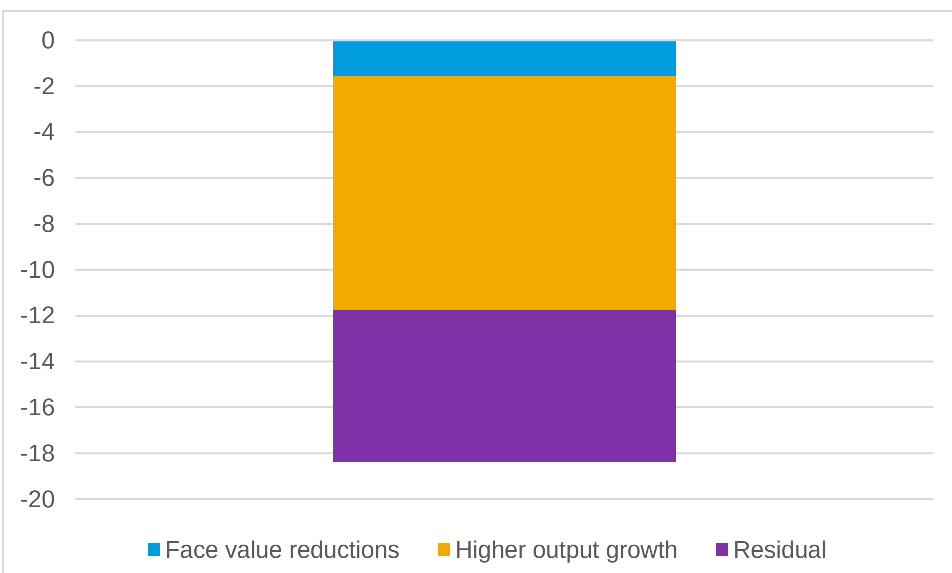
(A) Growth decomposition

(average annual contribution to growth, 1990-1999 vs. 1985-1989)



(B) Debt decomposition

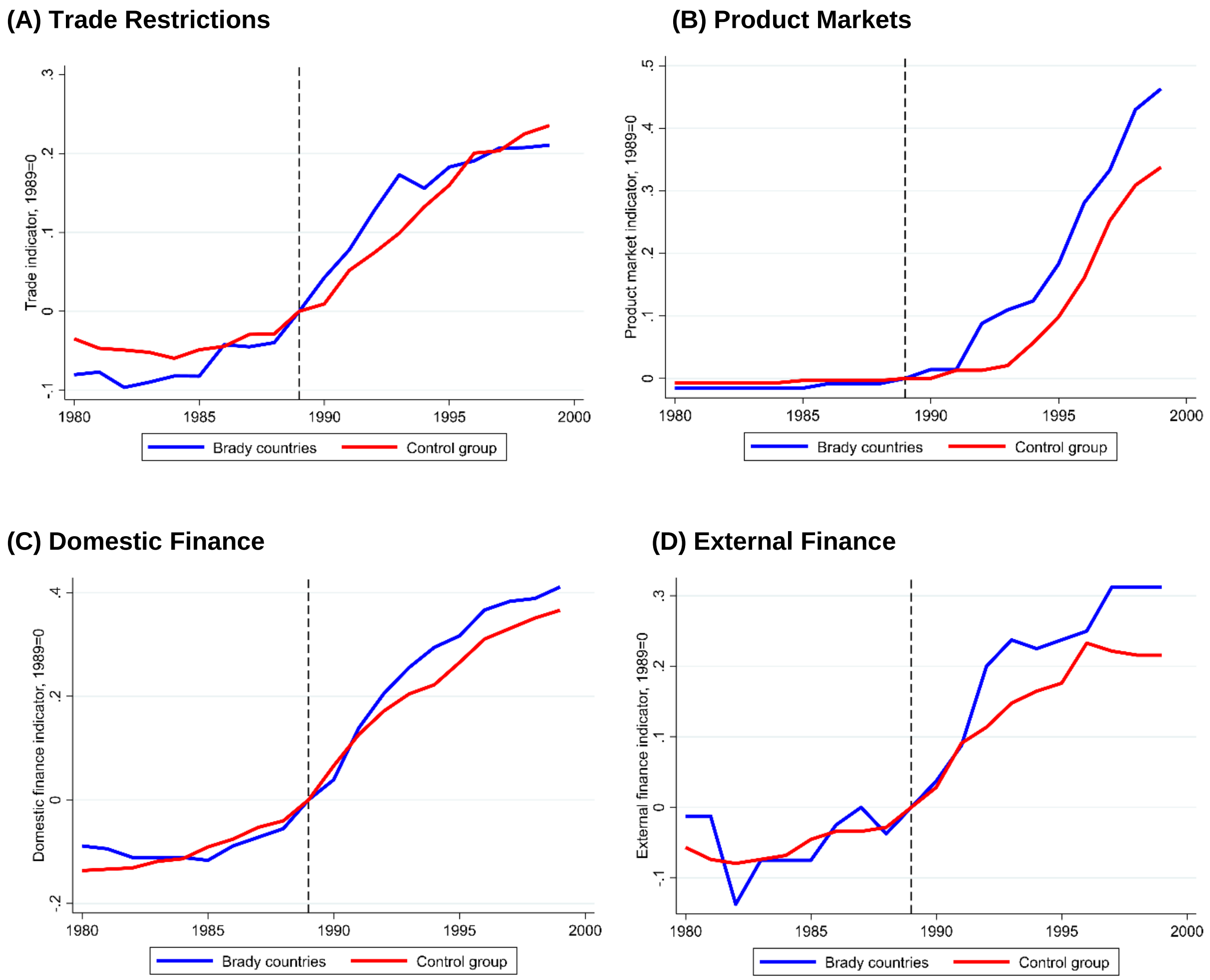
(average total change in gross government debt to GDP relative to control group, 1989-1999)



[1] Growth data from PWT 10.0. See Annex for details on growth and debt decompositions.

Figure 7. Reforms in Brady Restructurers vs. Comparators

(1989 = 0 for both groups)



Source: IMF Structural Reforms Database and author calculations

Higher total factor productivity growth was the main driver of the pick-up in economic growth following the Brady restructurings. In the 1980s, average growth of total factor productivity was negative in Brady countries. Output growth was mainly driven by population growth and output per capita stagnated. In the decade following the first Brady deal, TFP growth increased by 2.5 percentage points per year (Figure 6, Panel A).[18] The pick-up in market access of Brady countries, anchored by the marketability of collateralized

[18] Capital deepening (measured as the change in the capital to output ratio, see Annex I) contributed negatively to growth in Brady countries. This result may indicate that the increase in TFP growth in Brady countries was labor-biased.

restructured instruments and assured interest payments, may have contributed to this boost in total factor productivity growth as well as investment, as mentioned above.[19]

Brady countries achieved better macroeconomic performance compared to both other countries that restructured during the same period and countries that did not restructure. Annex Table 1 shows output for separate regressions that use only other restructurings (countries that underwent a non-Brady restructuring between 1980 and 2007) and non-restructurings as control groups. Government debt and inflation fell by similar magnitudes in Brady countries compared to both control groups. External debt fell more relative to other restructuring cases. The growth impact of the Brady Plan was largest relative to other restructurings. These findings are suggestive that it was the Brady Plan itself, and not the macroeconomic context that gave rise to the restructuring, that led to the improvement of macroeconomic fundamentals in Brady countries.

The long-term impact of the Brady restructurings on debt levels was many times greater than the face value reductions. The average face value reduction of a Brady deal was 3.3 percent of 1999 GDP. With public debt levels of Brady countries 20 percentage points lower in 1999 relative to the control group, and attributing this difference to the Brady Plan, this implies a ‘Brady multiplier’ of about 6 times the initial face value reduction. More than half of this effect is accounted for by the marked increase in output growth (Figure 6, Panel B).

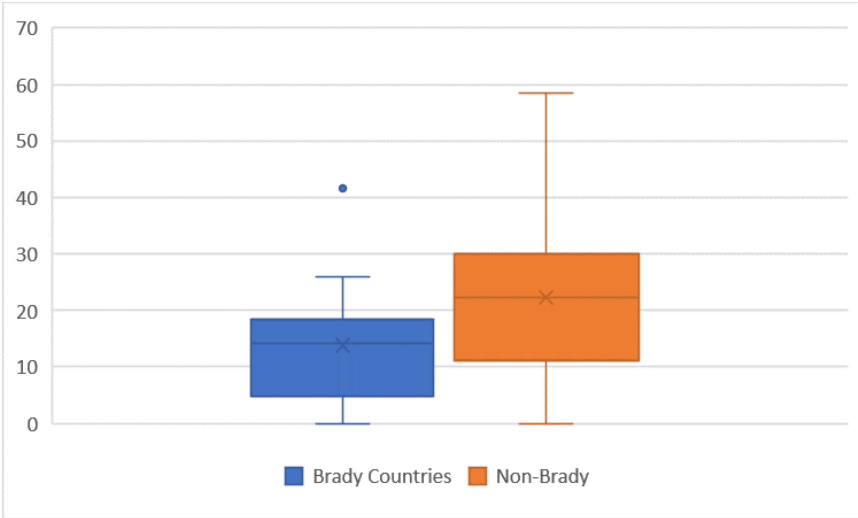
Brady countries undertook more ambitious structural reforms than non-Brady restructurers. One of the potential explanations of higher TFP growth in Brady restructurers could relate to their successful implementation of structural reforms relative to non-Brady restructurers. Furthermore, Brady countries made more progress on product market reforms relative to non-Brady. Brady countries also achieved greater levels of financial deepening, as evidenced by their better performance on both domestic and external finance (see Figure 7).[20] Furthermore, Brady countries tended to meet more of their IMF program quantitative targets relative to non-Brady peers, indicating a generally higher quality of macroeconomic policymaking in Brady countries (see Figure 8). These results would indicate that the structural reform efforts of Brady countries were greater than non-Brady countries.

[19] The pick-up in market access after Brady deals is documented in Henry and Arslanalp (2005), who show that Brady countries experienced a subsequent increase in net resource transfers (net resource flows minus interest payments on long-term loans and foreign direct investment profits).

[20] The sample of countries with data on structural reforms is too small to evaluate these differences statistically, but the magnitudes suggest these differences are economically meaningful. For example, between 1989 and 1999, the difference in product market standards widened by about one half of a standard deviation.

Figure 8. IMF Program Performance in Brady Restructurers vs. Comparators[1]

(Percentage of QPCs breached during IMF programs 1993-2002)



Source: IMF MONA database and author calculations.

[1] Variable measures the share of quantitative performance criteria (QPC) that were either not met or for which a waiver was requested. Average per country between 1993 and 2002. QPCs that were modified are not included. Brady countries includes all listed in Table 1 excluding Nigeria. Non-Brady countries include all other countries in MONA database between 1993 and 2002.

Robustness checks

Baseline difference-in-differences (DiD) results are in line with the results of a synthetic control method (SCM). The key assumption in the DiD method is that, in the absence of treatment (a Brady restructuring) the average outcomes in both treated and control groups follow "parallel trends", i.e., in the absence of treatment the difference between Brady and non-Brady countries would be constant over time. The pre-trends in Figures 3-6 are broadly parallel. As a robustness check, a synthetic control method is employed, which broadly confirm the results obtained in the DiD regression (see Figure 9). Indeed, the SCM results show that Brady restructurers had more favorable outcomes compared to synthetic controls on public debt, external debt, real GDP growth, and inflation. Brady restructurers also saw an increase in trade openness and their FDI stock relative to the synthetic control. They also experienced a faster and larger turnaround in their current account balances around 1993.

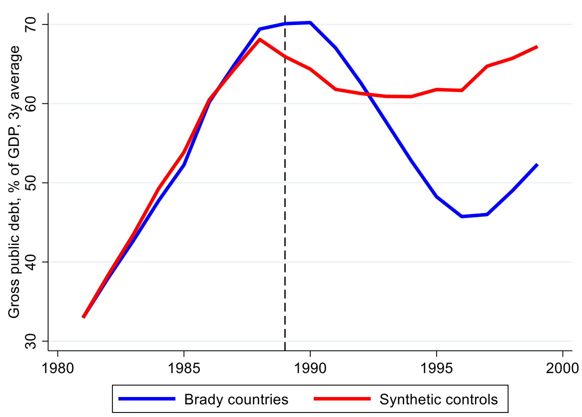
Accounting for variation in the timing of Brady restructurings confirms the main findings of the paper. We summarize results from a staggered DiD in Figures 12 and 13, which are consistent with the original DiD presented previously. The staggered treatment, which studies the impact of Brady restructurings before and after the start of the Brady restructuring (see Table 1), showed some improvement in the years running up to the Brady exchanges. This improvement could reflect confidence effects provided by the announcement of the Brady Plan, of which Arslanalp and Henry (2005) provide evidence. Another potential explanation is that the prior actions taken by Brady restructurers, including through the Baker Plan and other policy actions required to achieve UCT-quality IMF programs, yielded early dividends prior to the agreement of debt relief under the Brady Plan.

Figure 9. Evolution of Macroeconomic Outcomes Following the First Brady Deal (1980-1999)

(Synthetic Control Method)

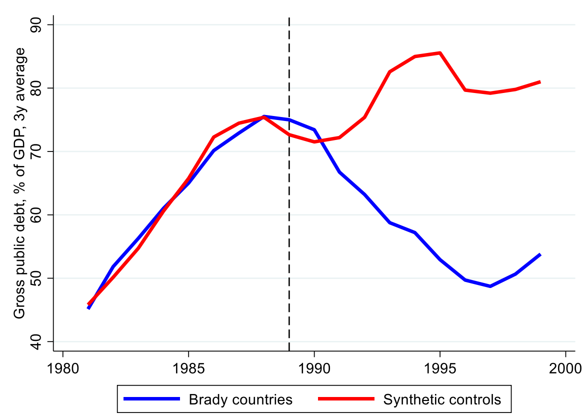
(A) Public debt, % of GDP

(3y average, deviation from 1989)



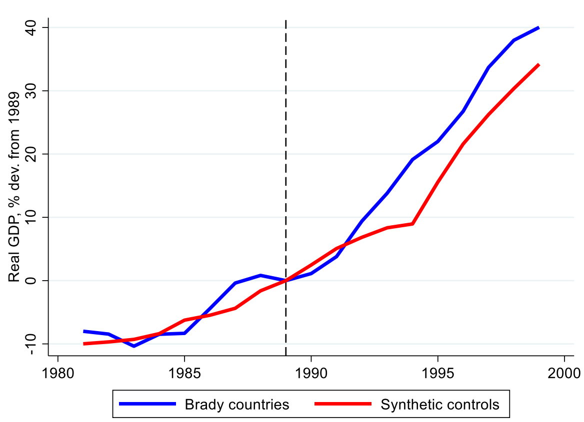
(B) External debt, % of GDP

(3y average, deviation from 1989)



(C) Real GDP

(% deviation from 1989)



(D) Inflation

(3y average of GDP deflator growth, %)

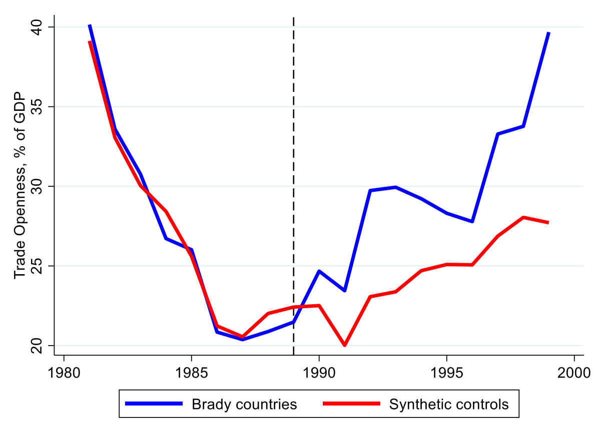
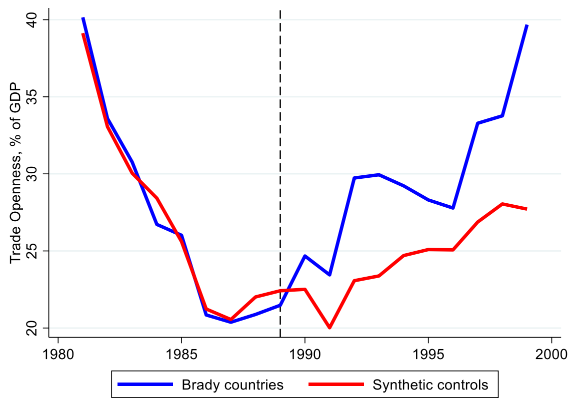


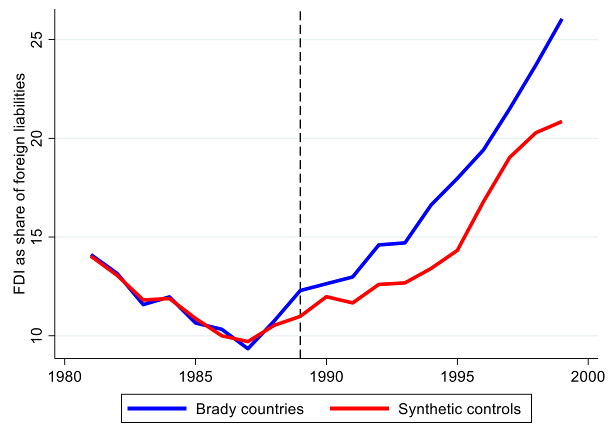
Figure 9. Evolution of Macroeconomic Outcomes Following the First Brady Deal (1980-1999) (continued)

(Synthetic Control Method)

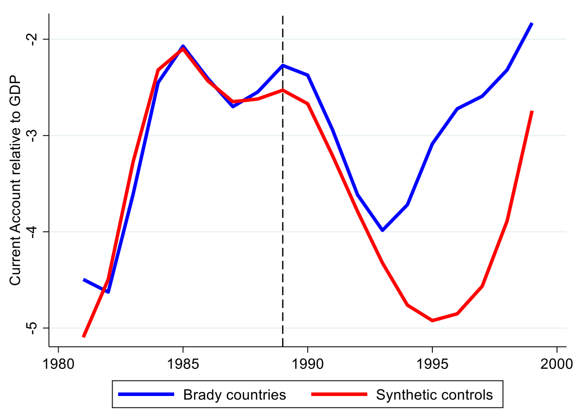
(E) Trade Openness, % of GDP



(F) FDI Stock (share of external liabilities)



(G) Current Account, % of GDP



(H) Net Investment Income, % of GDP

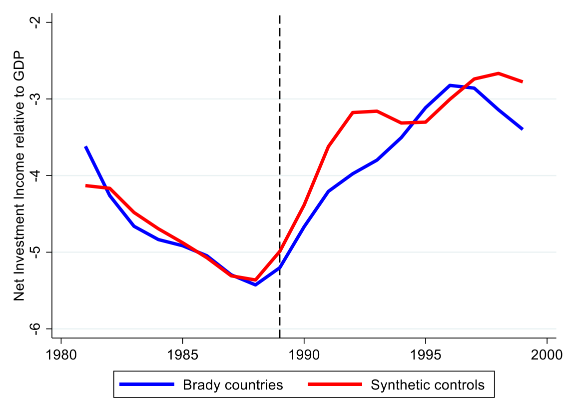
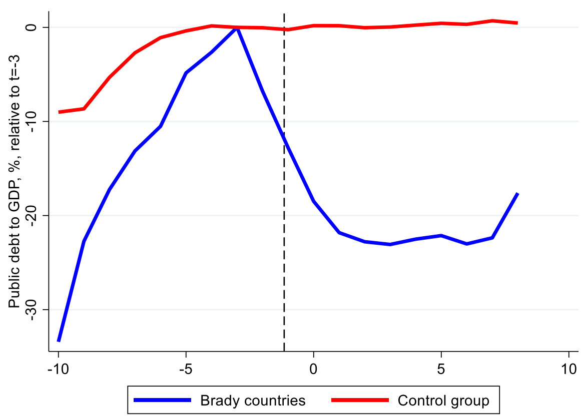


Figure 10. Evolution of Macroeconomic Outcomes Following the Brady Deals

(Differences-in-differences, Staggered)

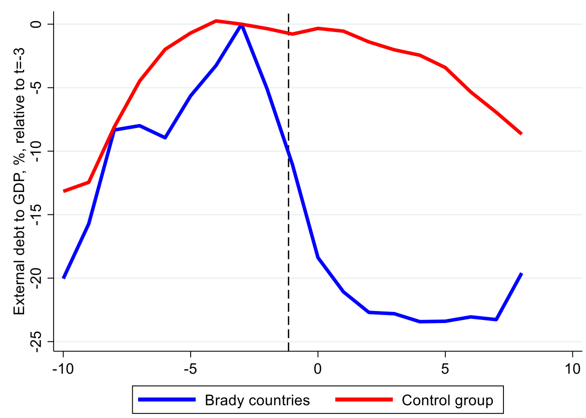
(A) Public debt, % of GDP

(3y av., dev. from 3 years before Brady deal)



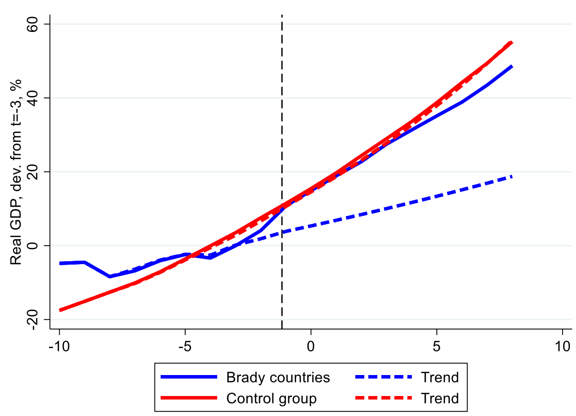
(B) External debt, % of GDP

(3y av., dev/ from 3 years before Brady deal)



(C) Real GDP

(dev. from 3 years before Brady deal)



(D) Inflation

(3y average of GDP deflator growth, %)

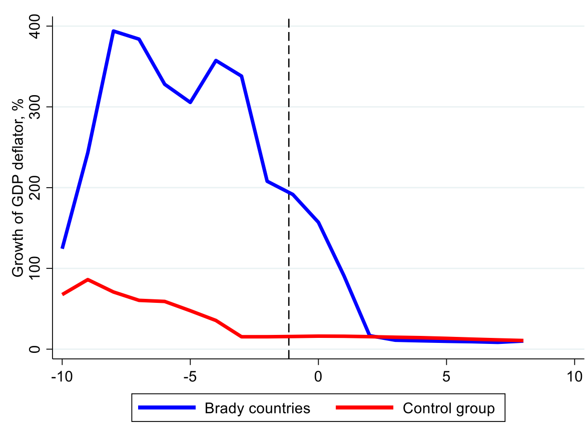
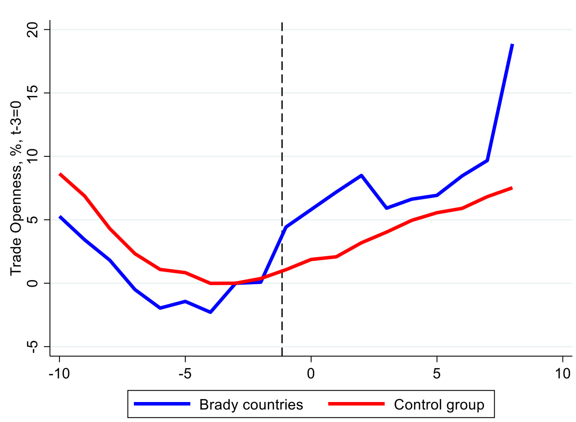


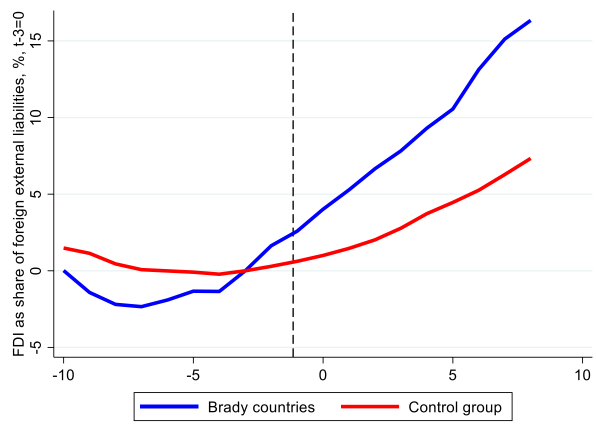
Figure 10. Evolution of Macroeconomic Outcomes Following the Brady Deals (continued)

(Differences-in-differences, Staggered)

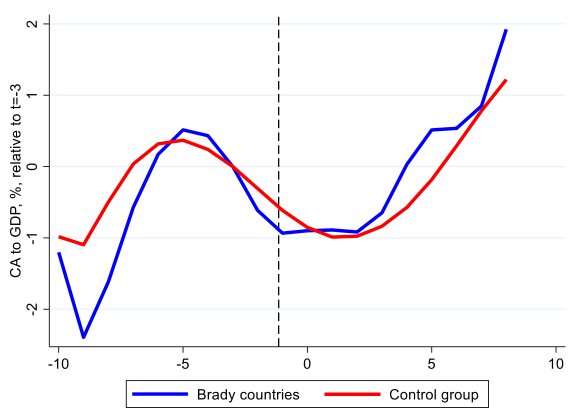
(E) Trade Openness, % of GDP



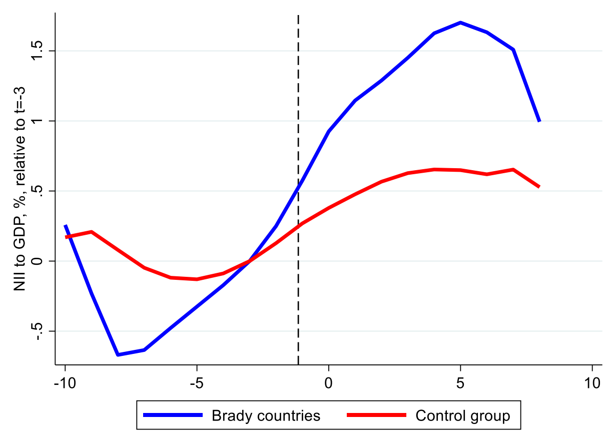
(F) FDI Stock (share of external liabilities)



(G) Current Account, % of GDP



(H) Net Investment Income, % of GDP



Discussion

The results of this paper are broadly consistent with other studies. For instance, Cheng, Diaz-Cassou, and Erce (2018) find that larger nominal debt relief in official Paris Club debt restructurings led to an acceleration of per-capita income growth, which is consistent with this paper's findings that Brady exchanges (with relatively larger debt relief) contributed to faster growth than compared to non-Brady comparators. This paper confirms the findings of Ando, Asonuma, Mishra, and Sollaci (2023), who find that restructurings with different types of creditors (external private, official, domestic) with face value reductions and stronger creditor coordination (conditions prevalent during the Brady period) were more effective in reducing debt-to-GDP ratios. Arslanalp and Henry (2005) find that the real value of stock markets in Brady countries appreciated by 60 percent relative to non-Brady countries after announcements of debt relief, which is consistent with this paper's findings regarding productivity growth (which would imply greater asset market returns). Reinhart and Trebesch (2016) estimate that Brady countries experienced a substantial reduction in public debt levels and significantly faster economic growth after the first Brady restructuring in 1990, which is also confirmed by this paper's baseline DiD and robustness check results. By contrast, the results of this paper challenge arguments made by Vásquez (1996), who highlighted that non-Brady reformers, such as Colombia and Chile, tended to have strong performance despite not receiving a Brady treatment. The results also contrast with the analysis of Berthélemy & Lensin (1992), who found heterogeneity in the economic performance of Brady restructurers and argued that the short-term growth effects of Brady restructurings were limited.

While these findings would suggest a correlation between Brady deals and favorable debt and macroeconomic outcomes, results should be interpreted with caution. The results indicate that countries that engaged in Brady exchanges achieved better outcomes than the control group, but it should be acknowledged that this paper's results do not provide clear evidence about which elements of Brady restructurings—such as pre-Brady reforms, face value haircuts, UCT-quality IMF programs, regained market access, and broadly favorable macroeconomic conditions in the 1990s—were decisive. Based on the results of this paper, it is possible that the depth of reforms and haircuts together may have led to better outcomes in Brady restructurers than compared to the control group. That said, it is likely that different aspects of the Brady package had different effects on specific outcomes. Face value write-downs may have proximately contributed to the decline in Brady country debt stocks, while reforms anchored by IMF programs and World Bank engagement may have contributed to a stronger structural reform effort and thus faster TFP growth, for instance. To the extent that the combination of the reduction in debt overhangs and stronger structural reform efforts combined to produce better results in Brady restructurers, then it follows that debt relief efforts coupled with renewed structural reforms in debtors can maximize benefits of restructuring and face value haircuts.

Brady-style restructuring mechanisms could be helpful in delivering meaningful debt stock reduction when solvency challenges are acute, as they were in the Brady period. In general, debt operations require an ex-ante assessment about whether a sovereign is experiencing liquidity or solvency challenges, which risk either Type I or Type II errors in debt relief. Liquidity operations attempt to provide near-term debt service relief to the troubled sovereign (e.g., via the Baker Plan), while solvency operations seek to restore solvency by reducing the face value of existing debt, with larger haircuts (e.g., the Brady Plan). Ex-post economic performance can validate the appropriateness of each ex-ante judgment. Trouble emerges either when debt servicing problems are diagnosed as a solvency challenge, when in fact liquidity relief would have restored sustainability (i.e., a Type 1 error, or false positive of the necessity of a Brady treatment), or when liquidity relief is offered while face value write-downs were in fact needed (i.e., a Type 2 error, or false negative, see Figure

12). In cases where the downside risks of providing too little relief are assessed to be greater than providing too much relief (i.e., where risks of a Type 2 error outweigh a Type 1 error), Brady-style exchanges may be useful because they historically were accompanied by larger debt stock reduction compared to other restructuring and reprofiling options—such as debt service suspension—and were anchored by enhancements to debtors' capacity-to-repay via reforms as well as credit enhancements that, at least during the Brady period, helped incentivize creditors to provide larger face value haircuts.[21] These mechanisms could also be used to facilitate pre-default restructurings when solvency challenges are acute, which can mitigate cumulative output losses (see Asonuma, Chamon, Erce, and Sasahara (2023)).

Figure 12. Managing Tradeoffs in Debt Restructuring Given Uncertainty

		***Ex-ante*[1]**	
		Liquidity	*Solvency*
Ex-post	*Liquidity*	Correct	Type I error (false positive)
	Solvency	Type II error (false negative)	Correct

[1]Debt operations require an ex-ante judgment about whether the sovereign's challenges reflect illiquidity or insolvency.

Source: Authors

However, Brady-style restructurings would not be a panacea to solve debt sustainability and debt restructuring challenges today. The results of this paper show that the Brady Plan's success applied to debtors under specific conditions relating to, inter-alia, countries that previously had market access and had been targets for the original Baker Plan due to commercial banks' outsize exposure to them; creditors' desire to achieve assurances about debtors' capacity-to-repay via policy adjustment and collateralization; existing claims that would benefit from enhanced liquidity and securitization; debtors willing to undertake ambitious reforms anchored by strong performance under IMF programs to achieve debt relief; and creditors willing to provide substantial face value relief. Critically, most Brady restructurers also had a modicum of institutional strength relative to, for instance, HIPC restructurers.[22] Brady deals also took place during a time of strong global economic growth and a relatively favorable commodity price outlook, which can be contrasted to the tepid growth outlook and uncertain commodity price outlooks today. While Brady exchanges could be useful tools in a diverse toolkit to facilitate sovereign debt restructuring, Brady-style mechanisms alone would not solve existing challenges in the sovereign debt landscape today, including those related to creditor coordination, debtors' weak institutional capacity coupled with political economy challenges that prevent structural reforms, and some countries' reliance on domestic debt, among others. Progress in these areas is being made under separate efforts, such as through the G20's Common Framework for Debt Treatments beyond the DSSI and the Global Sovereign Debt Roundtable (see G20 and Paris Club (2020) and Global Sovereign Debt Roundtable

[21] As explained by (Chuku, et al., 2023), to date, even though solvency and liquidity challenges have risen for LICs, they are generally better today than in the pre-HIPC period.

[22] See Arslanalp and Henry (2006).

(2023)).[23] Moreover, many debt vulnerable countries today are LICs with external debt held by official sector creditors. More work would need to be done to assess the potential benefits of collateralized restructured instruments for these types of debtors, including those that lacked market access prior to experiencing debt challenges.

Conclusions

The Brady Plan helped achieve fast and durable debt stock reduction, with macroeconomic dividends for debtors. Brady-style exchanges led to significant and persistent declines in public and external debt for Brady restructurers relative to the control group. Additionally, Brady restructurers saw broadly better macroeconomic outcomes, including faster growth, relative to the non-Brady control group. Taken together, the 'multiplier' effect of the face value reductions on debt burdens of the Brady countries was particularly large, making a Brady-style mechanism an effective tool for debt relief. This result is consistent with recent research on debt reductions, including as discussed in International Monetary Fund (2023) and Ando, Asonuma, Mishra, and Sollaci (2023).

The Brady Plan allowed for illiquid and non-transparent claims were be converted to marketable securities, with liquidity benefits for creditors and debtors. Brady exchanges also allowed for a diversification of the sovereign creditor base, from commercial banks, which tended to hold debt to maturity, to capital markets, in which there was active buying and selling in the restructured claims. One of the key benefits of the original Brady Plan was strengthening the liquidity of restructured claims while reducing creditor concentration (Miles, 1999).[24] Brady bonds thus opened new categories of institutional investors that would be attracted to the relatively higher returns offered by Brady bonds while still seeking the safety provided by their collateralized structure.[25]

Policy commitments achieved through the Brady Plan helped foster macroeconomic sustainability and safeguard reform momentum among debtors. The empirical results of this paper show that Brady restructurers had more favorable outcomes relative to the control group, driven mainly by the sharp pick-up in productivity growth and likely anchored by strong structural reform efforts of Brady countries in the 1990s. IMF programs and macroeconomic stabilization programs likely served as commitment devices of Brady restructurers to undertake needed but potentially difficult-to-implement reforms. Overall, Brady restructurers structural reform effort was stronger than peer countries.[26]

Future research could examine why the Brady Plan was relatively more successful than other debt relief initiatives while also employing complementary analytical methods. An additional avenue of future research could compare the Brady Plan and the Heavily Indebted Poor Country (HIPC) debt relief initiative, Multilateral Debt Relief Initiative, and the Vienna Initiative. This research could build on the work done by

[23] For a good summary of the IMF's views on the sovereign debt restructuring architecture, including some limitations, see IMF (2020). See also (Dielmann, 2021) for a summary of the recent rise in cross-border lending by non-Paris Club creditors, as well as an assessment of the terms and implications of such lending.

[24] Of course, creditors may need to overcome domestic legal constraints that would hamper their willingness to convert existing bilateral loans into tradeable bonds, such as obtaining parliamentary approval.

[25] This potential benefit is further evidenced by the fact that external sovereign bonds generally offer returns in excess of the compensation for the risk of default, while the same may not necessarily be true for bilateral claims (Meyer, Reinhart, & Trebesch, 2022).

[26] Such improvements in restructurers' institutional contexts and reform momentum are key distinguishing features of Brady restructurings compared to other debt relief efforts, such as HIPC.

Arslanalp and Henry (2006), who showed that debt relief alone is not a panacea for growth. Often, the barriers to growth in distressed sovereigns is not principally debt overhang, but instead follow from their low institutional quality. Thus, the most likely success stories of debt relief will be countries with a minimum level of institutional quality or those with a willingness to enhance their institutional quality. One avenue of future research could attempt to disambiguate further the relative weights of the drivers of favorable macroeconomic outcomes in Brady restructurers compared to other cases of debt restructuring. Indeed, the present study shows that the suite of reforms and write-downs undertaken and provided via Brady restructurings combined to provide better outcomes than in cases that did not have similar treatments. Additionally, future research can try to extend the political economic analysis of Brady restructurers to understand why their structural reform were stronger than non-Brady countries. In so doing, additional granularity on the types and quality of structural reforms pursued can be obtained. Finally, future research can use different empirical methods, including a permutation-based inference to better tease out causal links and weight caps in SCM calculations. It can also use more case studies of individual Brady cases for granularity.

Future research can also consider how Brady exchanges can complement existing debt restructuring mechanisms. This paper showed that Brady restructurings helped deliver good outcomes for emerging markets with a strong structural reform effort who had illiquid debts that would benefit from capacity-to-repay assurances (via IMF programs and collateral) and securitization, including for market development. There could be debt restructuring cases for which similar conditions apply today, and in those cases, Brady-style exchanges could be considered. If there existed a demand from both creditors and debtors, it is possible that Brady-style debt restructurings could be incorporated existing multilateral frameworks, which can be a subject of future research. Future research can also perform more granular assessments of debt vulnerabilities and try to map these modalities to potential qualification in a rebooted Brady Plan, as well as assess how today's more shock-prone and uncertain global conditions may affect the implementation of a new Brady-style mechanism, including by altering the incentives of creditors, debtors, and sponsors differently.

Annex 1. Detailed Regression Results

Annex Table 1: Average Treatment Effects, Differences-in-Differences Regressions

Panel A

Dependent variable	**Gross government debt to GDP, %, 3y average**			**External debt to GDP, %, 3y average**		
Control group	All EMDEs	Restructurings	Non-Restructurings	All EMDEs	Restructurings	Non-Restructurings
$brady_i \times post_t$	-18.4* (10.2)	-19.7 (12.3)	-17.5 (10.9)	-19.4* (9.8)	-26.9** (10.9)	-13.8 (12.4)
Constant	64.5*** (1.0)	72.4*** (2.3)	59.9*** (1.7)	69.9*** (1.0)	82.4*** (2.0)	61.2*** (1.9)
Country fixed effects	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y
Observations	100	54	66	100	54	66
Countries	50	27	33	50	27	33
Adjusted R^2	.67	.65	.66	.62	.72	.52

Panel B

Dependent variable	**Real GDP relative to pre-1990 trend, %**			**Inflation rate of GDP deflator, 3y average**		
Control group	All EMDEs	Restructurings	Non-Restructurings	All EMDEs	Restructurings	Non-Restructurings
$brady_i \times post_t$	24.4** (9.8)	31.7*** (10.3)	19.0 (13.5)	-661* (342)	-660* (348)	-662* (346)
Constant	.14 (1.0)	-3.5* (1.9)	2.8 (2.0)	145*** (34.2)	257*** (64.4)	211*** (52.3)
Country fixed effects	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y
Observations	100	54	66	100	54	66
Countries	50	27	33	50	27	33
Adjusted R^2	.53	.15	.0	.22	.16	.18

Notes: Table summarizes regression results from simple differences-in-differences regressions, specified above. Robust standard errors clustered at the country level in parentheses. ***: significant at 1%; **: significant at 5%; *: significant at 10.

Panel C

Dependent variable	Trade Openness			FDI Stock		
Control group	All EMDEs	Restructurings	Non-Restructurings	All EMDEs	Restructurings	Non-Restructurings
$brady_i \times post_t$	11.9*** (4.4)	11.8** (4.5)	11.9** (5.0)	8.4*** (2.9)	8.7** (3.8)	8.2** (3.1)
Constant	28.7*** (.4)	29.1*** (.8)	27.2*** (.8)	17.5*** (.29)	13.8*** (.70)	19.7*** (.48)
Country fixed effects	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y
Observations	100	54	66	100	54	66
Countries	50	27	33	50	27	33
Adjusted R^2	.88	.93	.80	.72	.45	.80

Panel D

Dependent variable	Current Account, % of GDP, 3y average			Net Investment Income, % of GDP, 3y average		
Control group	All EMDEs	Restructurings	Non-Restructurings	All EMDEs	Restructurings	Non-Restructurings
$brady_i \times post_t$	.68 (1.5)	-.03 (1.5)	1.2 (2.1)	.64 (.74)	1.4 (1.1)	.02 (.80)
Constant	-2.7*** (.15)	-3.4*** (.28)	-1.9*** (.33)	-3.6*** (.10)	-4.8*** (.19)	-2.9*** (.13)
Country fixed effects	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y
Observations	100	54	66	100	54	66
Countries	50	27	33	50	27	33
Adjusted R^2	0.0	.24	0.0	.59	.61	.43

Notes: Table summarizes regression results from simple differences-in-differences regressions, specified above. Robust standard errors clustered at the country level in parentheses. ***: significant at 1%; **: significant at 5%; *: significant at 10.

Annex Table 2: Average Treatment Effects, Differences-in-Differences Regressions, Staggered Treatment

Panel A

Dependent variable	Gross government debt to GDP, %, 3y average			External debt to GDP, %, 3y average		
Control group	All EMDEs	Restructurings	Non-Restructurings	All EMDEs	Restructurings	Non-Restructurings
$brady_i \times post_t$	-10.2 (6.6)	-12.1 (7.5)	-8.8 (7.0)	-10.7 (8.9)	-14.0 (9.4)	-8.2 (9.8)
Constant	62.9*** (.08)	74.3*** (.21)	54.2*** (.15)	68.5*** (.11)	86.1*** (.26)	55.2*** (.20)
Country fixed effects	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y
Observations	820	360	480	820	360	480
Countries	50	27	33	50	27	33
Adjusted R^2	.87	.86	.86	.86	.87	.82

Panel B

Dependent variable	Real GDP relative to pre-1990 trend, %			Inflation rate of GDP deflator, 3y average		
Control group	All EMDEs	Restructurings	Non-Restructurings	All EMDEs	Restructurings	Non-Restructurings
$brady_i \times post_t$	12.6** (5.3)	15.8*** (5.4)	10.2 (7.3)	-180 (165)	-179 (167)	-180 (166)
Constant	1.0*** (.06)	-3.1*** (.15)	4.3*** (.15)	19.3*** (2.0)	27.6*** (4.6)	20.1*** (3.5)
Country fixed effects	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y
Observations	820	360	480	820	360	480
Countries	50	27	33	50	27	33
Adjusted R^2	.55	.63	.52	.53	.52	.52

Notes: Table summarizes regression results from differences-in-differences regression with staggered treatment. Post period refers to the 5th year after the pre-treatment (restructuring) year. Robust standard errors clustered at the country level in parentheses. ***: significant at 1%; **: significant at 5%; *: significant at 10.

Panel C

Dependent variable	**Trade Openness**			**FDI Stock**		
Control group	All EMDEs	Restructurings	Non-Restructurings	All EMDEs	Restructurings	Non-Restructurings
$brady_i \times post_t$	-1.7 (3.2)	-3.2 (3.6)	-.58 (3.3)	3.6** (1.6)	3.9* (2.1)	3.4* (1.8)
Constant	30.1*** (.04)	31.3*** (.10)	29.2*** (.07)	17.6*** (.02)	12.9*** (.06)	21.1*** (.04)
Country fixed effects	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y
Observations	820	360	480	820	360	480
Countries	50	27	33	50	27	33
Adjusted R^2	.94	.94	.94	.89	.67	.92

Panel D

Dependent variable	**Current Account**			**Net Investment Income**		
Control group	All EMDEs	Restructurings	Non-Restructurings	All EMDEs	Restructurings	Non-Restructurings
$brady_i \times post_t$	.92 (1.5)	.87 (1.5)	.96 (1.6)	.67 (.60)	1.0 (.77)	.38 (.60)
Constant	-3.7*** (.02)	-4.8*** (.04)	-2.8*** (.04)	-3.1*** (.01)	-4.7*** (.02)	-1.8*** (.01)
Country fixed effects	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y
Observations	820	360	480	820	360	480
Countries	50	27	33	50	27	33
Adjusted R^2	.61	.65	.53	.85	.87	.51

Notes: Table summarizes regression results from differences-in-differences regression with staggered treatment. Post period refers to the 5th year after the pre-treatment (restructuring) year. Robust standard errors clustered at the country level in parentheses. ***: significant at 1%; **: significant at 5%; *: significant at 10.

Annex II. Brady Options

1980s-1990s Brady menu

Option	Enhancements	Restructured obligations
Buyback	Up-front cash payment	N/A
Par exchange transaction	Principal prepayment and up to 12% of remaining interest	Securitized with a fixed income stream at about 6.25% or less depending on term structure at time of deal. Generally, a 6.25% coupon payment was less than the prevailing rate on the original debt, thus providing cash flow and NPV relief to the borrower.
Discount exchange transaction	Principal prepayment and up to 13% of remaining interest	Securitized with a floating interest stream at LIBOR + 13/16 plus 30-35% face value haircut on the original obligations.
Temporary interest reduction exchange	Prepayment of up to 10% of remaining interest	Securitized with a submarket fixed income stream for first 5-6 years, followed by a floating interest rate of LIBOR + 13/16 as well as amortization of principal.
Debt conversion/new money	New loans equal to about 20% of the existing exposure of creditors	Securitized with an interest rate of LIBOR + 7/8 and amortization of principal repayments (based on the original amount).

Source: (Clark, 1994)

Other authors' proposed 2020s Brady menu (indicative)

Source	Option	Enhancements	Restructured obligations
Buchheit and Lerrick (2023)	Cash down-payment structure	Investors receive 30-35% up front of the bond's current market value	3-3.5% interest rate with 25-30 year maturity, amortization of original principal due in final 3 years
Buchheit and Lerrick (2023)	Floor of support structure	Collateralized with a zero-coupon World Bank bond	New bond has initial value of 60-70% of bond's current market value, with the minimum value rising to 100% of the nominal amount of the original (i.e., non-restructured) claims at maturity. 3-3.5% interest rate with 35-40 year maturity.
Coulibaly and Abedin (2023)	Recovery and Sustainability bonds (RSBs)	RSBs have preferred creditor status and are collateralized by zero-coupon bonds issued by, for example, the World Bank	30% haircut on outstanding private external debt. RSBs have 5% coupon rate with 30-year maturities, with fully amortized principal.
Qian (2021)	IFI or sovereign guarantee	IFI guarantees principal and interest rate of collateralized borrowing structure	Restructured bonds have haircuts and SCDI (e.g., commodity)-linked features

Sources: (Buchheit & Lerrick, 2023), (Coulibaly & Abedin, 2023), (Qian, 2021)

References

Abadie, A., & Gardeazabal, J. (2003). The Economic Costs of Conflict: A Case Study of the Basque Country. *American Economic Review, 93*(1), 112-132.

Abadie, A., Diamond, A., & Hainmueller, J. (2010). Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Control Program. *Journal of the American Statistical Association, 105*(490), 493-505.

Adhikari, B., & Alm, J. (2016). Evaluating the Economic Effects of Flat Tax Reforms Using Synthetic Control Methods. *Southern Economic Journal, 83*(2), 437-463.

Adhikari, B., Duval, R. A., Hu, B., & Loungani, P. (2016). Can Reform Waves Turn the Tide? Some Case Studies Using the Synthetic Control Method. *IMF Working Papers, 16*(171), 1-35.

Ando, Sakai and Asonuma, Tamon and Mishra, Prachi and Sollaci, Alexandre, Sovereign Debt Restructuring and Reduction in Debt-to-GDP Ratio (September 30, 2023).

Arslanalp, S., & Henry, P. B. (2005). Is Debt Relief Efficient? *The Journal of Finance, 60*(2), 1017-1051.

Arslanalp, S., & Henry, P. B. (2006). Policy Watch: Debt Relief. *Journal of Economic Perspectives, 20*(1), 207-220.

Asonuma, T., Chamon, M., Erce, A., & Sasahara. (2021). A. *Costs of Sovereign Defaults: Restructuring Strategies and Financial Intermediation*.

Asonuma, T., & Trebesch, C. (2016). Sovereign Debt Restructurings: Preemptive or Post-Default. *Journal of the European Economic Association, 14*(1), 175-214.

Baker, A., Larcker, D. F., & Wang, C. C. (2021). How Much Should we Trust Staggered Difference-in-Differences Estimates? *Harvard Business School Working Papers*, 1-69.

Baqir, R., Ramcharan, R., & Sahay, R. (2005). IMF Programs and Growth: Is Optimism Defensible? *IMF Staff Papers*, 260-286.

Beaudry, P., & Willems, T. (2022). On the Macroeconomic Consequences of Over-Optimism. *American Economic Review, 14*(1), 38-59.

Becker, B., & Ivashina, V. (2014). Reaching for Yield in the Bond Market. *The Journal of Finance, 70*(5), 1863-1902.

Berthélemy, J.-C., & Lensink, R. (1992). An Assessment of the Brady Plan Agreements. *OECD Development Center*(67), 1-44.

Billmeier, A., & Nannicini, T. (2013). Assessing Economic Liberalization Episodes: A Synthetic Control Approach. *The Review of Economics and Statistics, 95*(3), 983-1001.

Bogdanowicz-Bindert, C. A. (1986). The Debt Crisis: The Baker Plan Revisited. *Journal of Interamerican Studies and World Affairs, 28*(3), 33-45.

Born, B., Müller, G., Schularick, M., & Sedlacek, P. (2019). The Costs of Economic Nationalism: Evidence from the Brexit Experiment. *The Economic Journal, 129*(623), 2722-2744.

Buchheit, L. C., & Lerrick, A. (2023). *A Modern Template for the Restructuring of Poor Country Debts.*

Cheng, Gong and Diaz-Cassou, Javier and Erce, Aitor, Official Debt Restructurings and Development (2018-04-20). Globalization and Monetary Policy Institute Working Paper No. 339.

Chuku, C., Samal, P., Saito, J., Hakura, D., Chamon, M., Cerisola, M., . . . Zettelmeyer, J. (2023). Are We Heading for Another Debt Crisis in Low-Income Countries? Debt Vulnerabilities: Today vs. the pre-HIPC Era. *IMF Working Papers, 23*(79), 1-41.

Clark, J. (1994). Debt Reduction and Market Reentry under the Brady Plan. *FRBNY Quarterly Review*, 38-62.

Cline, W. R. (1995). *International Debt Reexamined.* Washington, DC: Institute for International Economics.

Coulibaly, B. S., & Abedin, W. (2023). Addressing the Looming Sovereign Debt Crisis in the Developing World: It is Time to Consider a 'Brady Plan'. *Global Economy and Developmetn at Brookings*, 1-15.

Dielmann, C. (2021). *On Free-Riders and Sovereign Default: The Rise of Non-Traditional Bilateral Lenders and the Resulting Challenges to International Debt Renegotiations.* Baltimore, MD: Johns Hopkins University.

Economides, N., & Smith, R. C. (2011). Trichet Bonds to Resolve the European Sovereign Debt Problem. *NET Institute Working Papers, 11*(01), 1-7.

EMTA. (2022). *Trade Association for the Emerging Markets*. Retrieved from The Brady Plan: https://www.emta.org/em-background/the-brady-plan/

Feenstra, R. C., Inklaar, R., & Timmer, M. P. (2015). The Next Generation of the Penn World Table. *American Economic Review, 105*(10), 3150-82.

G20 and Paris Club. *Common Framework for Debt Treatments beyond the DSSI* (2020).

Global Sovereign Debt Roundtable. 2023. *Global Sovereign Debt Roundtable Cochairs Progress Report*.

Gumbau-Brisa, F., & Mann, C. L. (2009). Reviving Mortgage Securitizatoin: Lessons from the Brady Plan and Duration Analysis. *Federal Reserve Bank of Boston Public Policy Discussion Papers*, 1-49.

International Monetary Fund. (2021). *Fund Support for Debt- and Debt-Service Reduction Operations*. Washington, D.C.: IMF.

International Monetary Fund. (2023). *The International Architecture for Resolving Sovereign Debt Involving Private-Sector Creditors—Recent Developments, Challenges, And Reform Options*. Washington, D.C.: IMF.

International Monetary Fund. (2023). *World Economic Outlook: A Rocky Recovery.* Washington, D.C.: IMF.

Kuruc, K. (2022). Are IMF rescue packages effective? A synthetic control analysis of macroeconomic crises. *Journal of Monetary Economics, 127*(C), 38-53.

Lane, P. R., & Milesi-Ferretti, G. (2018). The External Wealth of Nations Revisited: International Financial Integration in the Aftermath of the Global Financial Crisis. *IMF Economic Review, 66*, 189-222.

Lang, V., Mihalyi, D., & Presbitero, A. F. (n.d.). Borrowing Costs after Sovereign Debt Relief. *American Economic Journal (forthcoming)*.

Mbaye, S., Moreno Badia, M., & Chae, K. (2018). Global Debt Database: Methodology and Sources. *IMF Working Papers, 18*(111), 1-52.

Meyer, J., Reinhart, C. M., & Trebesch, C. (2022). Sovereign Bonds since Waterloo. *NBER Working Paper Series*(25543).

Miles, W. (1999). Securitization, liquidity, and the Brady plan. *The North American Journal of Economics and Finance, 10*(2), 423-442.

Nannicini, T., & Billmeier, A. (2011). Economies in Transition: How Important Is Trade Openness for Growth? *Oxford Bulletin of Economics and Statistics, 73*(3), 287-314.

Newiak, M., & Willems, T. (2017). Evaluating the Impact of Non-Financial IMF Programs Using the Synthetic Control Method. *IMF Working Papers, 17*(109), 1-43.

Qian, Y. (2021). Brady Bonds and the Potential for Debt Restructuring in the Post-Pandemic Era. *BU Global Development Policy Center Working Papers*(09), 1-23.

Reinhart, Carmen M., Vincent Reinhart, and Cristoph Trebesch. (2016). Global Cycles: Capital Flows, Commodities, and Sovereign Defaults. *American Economic Review, 106*(5), 574-80.

Shalal, A. (2023, April 25). *World Bank Chief Economist Gill Calls for New Approaches to Address 'Debt Crisis'.* Retrieved from Reuters: https://infodisplay.infodesk.com/item/c6b7e31f-4f30-4f21-a423-ffc54c2ef1ea.html?CU=imf5992&APP=6

Sims, J., & Romero, J. (2013, November 22). *Latin American Debt Crisis of the 1980s: 1982-1989.* Retrieved from Federal Reserve History: https://www.federalreservehistory.org/essays/latin-american-debt-crisis

Sturzenegger, F., & Zettelmeyer, J. (2006). *Debt Defaults and Lessons from a Decade of Crises.* Cambridge: MIT Press.

Trebesch, C., Meyer, J., Reinhart, C., & Grav von Luckner, C. (2021, March 30). *External sovereign debt restructurings: Delay and replay*. Retrieved from VoxEU.

Truman, E. M. (2020). Sovereign Debt Relief in the Global Pandemic: Lessons from the 1980s. *Peterson Institute for International Economics Working Papers*, 1-11.

Vásquez, I. (1996). The Brady Plan and Market-Based Solutions to Debt Crises. *Cato Journal, 16*(2), 233-243.

Wolf, M. (2022, January 17). *We must tackle the looming global debt crisis before it's too late.* Retrieved from Financial Times: https://www.ft.com/content/889fec5a-cb62-463f-af8c-22c841bddb65

PUBLICATIONS

How the Brady Plan Delivered on Debt Relief: Lessons and Implications

Working Paper No. WP/2023/258

Annex 528

"IMF-Adapted ND-GAIN Index", *International Monetary Fund Climate Change Dashboard*, 1 December 2023

IMF | CLIMATE CHANGE DASHBOARD

IMF-Adapted ND-GAIN Index

CID Admin
Private Organization

View Table More

Summary

The ND-GAIN index is a global free open-source index, that measures a country's current vulnerability to climate disruptions and assesses a country's readiness to leverage private and public sector investment for adaptive actions.

The IMF-adapted ND-GAIN index is an adaptation of the original index, adjusted by IMF staff to replace the Doing Business (DB) Index, used as source data in the original ND-GAIN, because the DB database has been discontinued by the World Bank in 2020 and it is no longer allowed in IMF work.

The IMF-adapted ND-GAIN is an interim solution offered by IMF staff until the ND-GAIN compilers will review the methodology and replace the DB index.

Sources: ND-GAIN; Findex - The Global Findex Database 2021; Worldwide Governance Indicators; IMF staff calculations.

Category: Financial and Risk Indicators

Data series:

- IMF-Adapted ND-GAIN Index
- IMF-Adapted Readiness score
- Readiness score, Governance
- Readiness score, IMF-Adapted Economic
- Readiness score, Social
- Vulnerability score
- Vulnerability score, Capacity
- Vulnerability score, Ecosystems

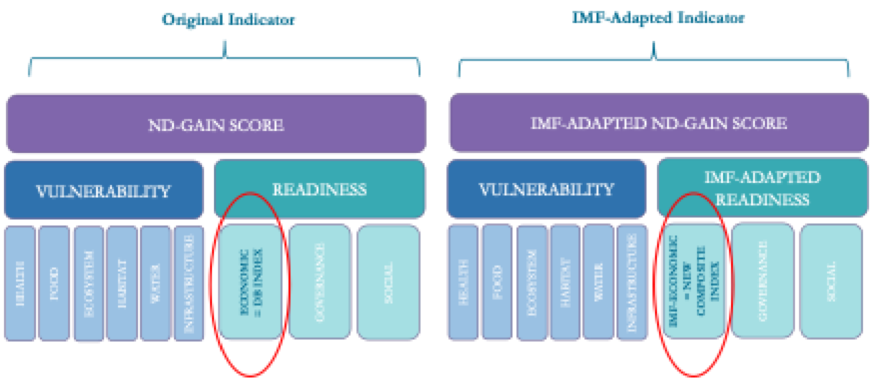
Add to Favorites Download

- Vulnerability score, Heath
- Vulnerability score, Sensitivity
- Vulnerability score, Water
- Vulnerability score, Infrastructure

Metadata:

The IMF-adapted ND-GAIN Country Index uses 75 data sources to form 45 core indicators that reflect the vulnerability and readiness of 192 countries from 2015 to 2021. As the original indicator, a country's IMF-adapted ND-GAIN score is composed of a *Readiness* score and a *Vulnerability* score.

The Readiness score is measured using three sub-components – *Economic*, *Governance* and *Social*. In the original ND-GAIN database, the Economic score is built on the DB index, while in the IMF-adapted ND-GAIN, the DB Index is replaced with a composite index built using the arithmetic mean of "Borrowed from a financial institution (% age 15+)" from The Global Financial Index database (FINDEX_BFI) and "Government effectiveness" from the Worldwide Governance Indicators database (WGI_GE). The Vulnerability, Social and Governance scores do not contain any DB inputs and, hence, have been sourced from the original ND-GAIN database.



Methodology:

The procedure for data conversion to index is the same as the original ND-GAIN and follows three steps:

Step 1. Select and collect data from the sources (called "raw" data), or compute indicators from underlying data. Some data errors (i.e., tabulation errors coming from the source) are identified and corrected at this stage. If some form of transformation is needed (e.g., expressing the measure in appropriate units, log transformation to better represent the real sensitivity of the measure etc.) it happens also at this stage.

make up for the missing data. In the second instance, the indicator is labeled as "missing" for that country, which means the indicator will not be considered in the averaging process.

Step 3. This step can be carried out after of before Step 2 above. Select baseline minimum and maximum values for the raw data. These encompass all or most of the observed range of values across countries, but in some cases the distribution of the observed raw data is highly skewed. In this case, ND-GAIN selects the 90-percentile value if the distribution is right skewed, or 10-percentile value if the distribution is left skewed, as the baseline maximum or minimum.

Based on this procedure, the IMF–Adapted ND-GAIN Index is derived as follows:
i. Replace the original Economic score with a composite index based on the average of WGI_GE and cubic root of FINDEX_BFI[1], as follows:

IMF-Adapted Economic = $\frac{1}{2} \cdot (WGI\_GE) + \frac{1}{2} \cdot (FINDEX\_BFI)^{1/3}$ (1)

The IMF-adapted Readiness and overall IMF-adapted ND-GAIN scores are then derived as:

IMF-Adapted ND-GAIN Readiness = 1/3 · (IMF-Adapted Economic + Governance + Social)
IMF-Adapted ND-GAIN = ½·(IMF-Adapted ND-GAIN Readiness+ND-GAIN Vulnerability)

ii. In case of missing data for one of the indicators in (1), **IMF-Adapted ND-GAIN Economic** would be based on the value of the available indicator. In case none of the two indicators is available, the **IMF-Adapted Economic** score would not be produced but the **IMF-Adapted ND-GAIN Readiness** would be computed as average of the Governance and Social scores. This approach, that replicates the approach used to derive the original ND-GAIN indexes in case of

Read Less

Adaptation

Attributes

Learn about charts

abc Country

abc ISO2

abc ISO3

Indicator

CTS Code

CTS Full Descriptor

2015

2016

2017

Load more

Details

Dataset
Table

December 1, 2023
Info Updated

December 1, 2023
Data Updated

July 27, 2023
Published Date

Records: 2,756
View data table

Public
Anyone can see this content

Custom License
View license details

I want to...

Create a Map
Start a map with this data

Create a Story
Open in ArcGIS StoryMaps

Annex 529

"Policy options to reduce the climate insurance protection gap", Discussion Paper, *European Central Bank,* April 2023

EUROPEAN CENTRAL BANK
EUROSYSTEM

European Insurance and Occupational Pensions Authority

Policy options to reduce the climate insurance protection gap

Discussion Paper

April 2023

Contents

Executive summary

Extreme weather and climate events can have significant macroeconomic implications. While the economic impact of such events in Europe has been manageable historically, it is expected to rise over time as catastrophes become more frequent and more severe due to global warming.

Catastrophe insurance is a key tool to mitigate macroeconomic losses following extreme climate-related events, as it provides prompt funding for reconstruction and should incentivise risk reduction and adaptation. The overall societal cost of a disaster depends not only on the severity of the initial damage but also on how swiftly reconstruction can be completed. However, reconstruction can be prolonged and may even be incomplete in the absence of sufficient resources. Insurance pay-outs reduce uncertainty and support aggregate demand and investment for reconstruction, enabling economies to recover faster and limiting the period of lower economic output. By contrast, without insurance, households and firms have to finance post-disaster recovery mainly with savings, credit and/or uncertain government relief, which is likely to be much less efficient.

Only about a quarter of climate-related catastrophe losses are currently insured in the EU. This insurance protection gap could widen in the medium to long term as a result of climate change, partly because repricing of insurance contracts in response to increasingly frequent and intense events may lead to such insurance becoming unaffordable. This would further increase the burden on governments, both in terms of macroeconomic risks and in terms of fiscal spending to cover uninsured losses. This may raise government debt burdens of EU countries and increase economic divergence. A widening insurance protection gap may also pose financial stability risks and reduce credit provision in countries with large banking sector exposures to catastrophe risk events.

This discussion paper sets out possible actions which should be considered to tackle this protection gap and mitigate catastrophe risks from climate change in the EU by means of insurance coverage and adaptation measures. These efforts should be complementary to ambitious mitigation policies to tackle climate change and reduce associated catastrophe risks, and should not be seen as a substitute for such policies. The actions discussed in this paper have been designed to fulfil the following main objectives:

- help provide prompt insurance claim pay-outs after a natural disaster;
- incentivise risk mitigation and adaptation measures;
- be complementary to existing insurance coverage mechanisms;
- require the sharing of costs and responsibilities across the relevant stakeholders to ensure “skin in the game” and reduce moral hazard;

- lower the share of economic losses from major natural disasters borne by the public sector over the long term.

The paper uses the term “ladder approach” in the context of indicating the share of losses from natural disasters borne by various parties at different loss layers. It builds on the existing frameworks of private insurance and public sector intervention, and discusses the case for some coordination of public sector efforts at the EU level. Private (re)insurance should be the first line of defence to cover losses from climate-related natural disasters. The use of financial markets to transfer risks via catastrophe bonds (cat bonds) may also support the reinsurance of such risks. However, as natural catastrophe risks are expected to grow and become more difficult to insure, policymakers need to consider putting in place more sophisticated frameworks to deal with extreme weather events and minimise future costs to taxpayers. These include public-private partnerships (PPPs) and ex ante public backstops – which could be reinforced by an EU-wide component – together with suitable safeguards and incentives to promote risk mitigation. The purpose of such approaches is not to provide blanket government guarantees for uninsured losses but to enhance efficiency in the use of public funds and reduce moral hazard relative to the typical status quo of unconditional government support after disasters.

While higher private insurance coverage is beneficial and desirable, insurance provision should be carefully designed to ensure that it encourages adaptation and reduces vulnerability to climate-related catastrophes over time. The design of insurance policies can provide incentives to policyholders for risk reduction and adaptation while limiting moral hazard (e.g. via impact underwriting). To this end, it is also essential that (re)insurers continue to incorporate climate change risks in their own risk management to ensure the long-term sustainability of their business model.

Capital market instruments, such as cat bonds, can complement insurance schemes to provide prompt liquidity for reconstruction after disasters. They can also help to pass on part of the tail risk assumed by private (re)insurers and/or PPPs to capital markets. Capital market instruments, which are often used together with traditional reinsurance, provide two key benefits: (i) diversification in the form of an alternative source of capital and (ii) a lower premium for overall coverage.

The public sector can prepare for contingent liabilities related to climate-related catastrophes by enhancing its ex ante disaster risk management strategy. This could include supporting ex ante contingent financing by creating fiscal buffers, such as national reserve funds. It could also include risk transfer and measures that support private insurance solutions, such as public-private insurance schemes that pool and diversify risks, or capital market products that transfer part of the risk to investors. Governments can support and encourage the development of an active market for the issuance and trading of cat bonds, for example by lowering issuance costs. Better measurement of fiscal expenditures related to climate-related extreme weather events would also help to manage fiscal risks and ensure better preparation before disasters occur.

PPPs at the national level can support the overall functioning of the insurance market by providing additional coverage either via direct insurance or by indemnifying a private (re)insurer against extraordinary events. While the private insurance sector can provide extensive expertise in prompt loss assessment and pay-outs, public authorities can improve the legal framework and act as a reinsurer of last resort. The design of PPPs should ensure that the costs and responsibilities associated with having a resilient catastrophe insurance coverage programme are shared between the public and private sectors. Furthermore, PPPs should leave a portion of the economic costs uninsured to limit moral hazard. Mandatory coverage (i.e. a requirement for everyone to insure against catastrophes) and/or mandatory offers (i.e. a requirement for insurers to offer catastrophe cover alongside, say, property insurance) could also help to tackle moral hazard. PPPs already exist in some European countries to manage specific disaster risks.

For less frequent, large-scale disasters, an EU-wide public scheme for natural disaster insurance covering a broad range of weakly correlated hazards could complement national schemes. Pooling risks at the EU level could help to reduce the economic costs of catastrophes and accelerate recovery and reconstruction efforts, while incentivising and promoting ex ante risk reduction via both mitigation and adaptation measures. Any EU-wide fund should be additional to existing funding for tackling climate change, and should have safeguards to address moral hazard, such as making access conditional on Member States implementing agreed adaptation strategies and meeting their emissions reduction targets. Such a fund would complement the EU's climate policies and related initiatives, such as the renewed sustainable finance strategy, and leverage on the experience from existing tools for disaster relief that are not currently adapted to increasing needs related to climate change, such as the EU Solidarity Fund (EUSF).

Wider EU policy initiatives, such as the capital markets union (CMU), could also help to further develop and integrate EU financial and insurance markets. This could improve the accessibility and size of the pool of private funding available to tackle the climate insurance protection gap.

Finally, in the banking sector, risks associated with a lack of insurance against climate-related disasters may trigger higher capital needs for existing lending and could lower credit supply. Targeted prudential/macroprudential regulations may therefore be needed to enhance the banking sector's resilience to the implications of a persistent climate insurance protection gap.

This discussion paper does not reach firm conclusions on specific policies that need to be implemented to tackle the climate insurance protection gap. Rather, its aim is to solicit feedback on the possible policy actions set out. The European Central Bank (ECB) and the European Insurance and Occupational Pensions Authority (EIOPA) will continue to undertake further analysis of these policy options, taking into account comments received on this paper.

The ECB and EIOPA would welcome comments and feedback on all aspects of this paper. Comments should be sent to this email, ideally by 15 June 2023: ecb_eiopa_staff_protection_gap@eiopa.europa.eu

Introduction

This discussion paper identifies policy options to tackle the widening climate insurance protection gap – i.e., the uninsured portion of the economic losses caused by climate-related natural disasters – while incentivising adaptation and mitigation in light of the expected increase in the frequency and severity of such events due to climate change. It argues for a ladder approach to natural catastrophe insurance, considering options for: (i) enhancing private insurance and deepening cat bond markets; (ii) developing possible shared resilience solutions between public and private entities at national level; and (iii) identifying risk pooling and diversification opportunities that could be explored at a European level.

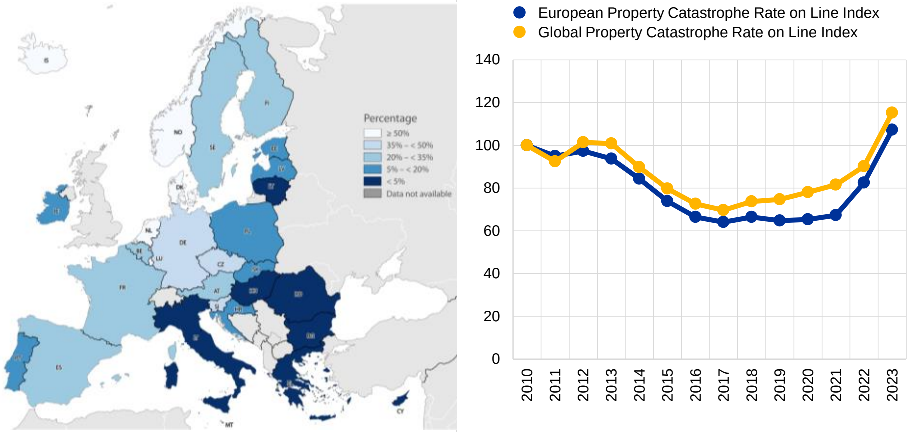
Such policies need to be considered alongside ambitious measures to tackle climate change and reduce associated catastrophe risks by cutting greenhouse gas emissions and transitioning towards a net zero economy, and should not be seen as a substitute for such measures. It is also not possible to insure against all catastrophe risks, nor would doing so be desirable in the context of incentivising adaptation to climate change.

Only about a quarter of the losses caused by extreme weather and climate-related events in the EU are currently insured, and in several countries this share is below 5%. (**Chart 1, left panel**). There are several structural reasons for this insurance protection gap, including underestimation of the likelihood and potential impact of catastrophes and moral hazard, for example if sovereigns are expected to cover residual uninsured losses after a catastrophe occurs.

Chart 1

The share of insured economic losses related to natural catastrophes in Europe is low and could decline in the medium to long term, while property catastrophe premium indicators have been increasing recently, albeit from historically low levels

Average share of insured economic losses caused by weather-related events in Europe	Guy Carpenter's Global and Continental Europe Property Catastrophe Rate on Line Index
(1980-2021, percentages)	(2010-2023, percentage growth)



Sources: Left panel: EIOPA dashboard on insurance protection gap for natural catastrophes, European Environment Agency (EEA) CATDAT; right panel: Guy Carpenter and Artemis.
Notes: The data points in the right panel indicate the Rate on Line charged at the beginning of each year.

Climate change poses several challenges for the provision of insurance. First, a greater frequency and severity of natural disasters could generate higher than foreseen claims, increasing insurers' underwriting and liquidity risks, and putting pressure on their solvency. In addition, changes in climate and weather, exacerbated by non-linearities and feedback loops that can accelerate the temperature rise, mean that past losses could become unreliable for estimating future losses. Climate change could also affect the randomness and correlation of events across regions or countries, reducing the potential to diversify underwriting portfolios. Finally, demand side issues for the uptake of insurance products should also be addressed. For instance, as consumers might not fully understand the coverage they buy, expectation gaps may arise, and consumers may not be aware of the actual protection gap in their policies.

As catastrophes become more frequent and more severe, insurance becomes more valuable from a macroeconomic and societal perspective (**Section 1**). At the same time, as insurance claims increase, premiums are likely to rise and/or coverage fall, thereby widening the protection gap (**Chart 1, right panel**). Swiss Re estimates that there were USD 120 billion of catastrophe losses globally in 2022, well above the past ten-year average of USD 81 billion. And six consecutive years of above-average losses have driven property catastrophe reinsurance prices higher in recent years, with European rates increasing by 30% at the January 2023 renewals according to the international brokerage group Howden. Besides damages from catastrophes, high inflation, the Russia-Ukraine conflict, and years of low interest rates have also contributed to the magnitude of recent price increases.

The design of private insurance policies can address these market failures to some extent (**Section 2.1**), for example by incorporating risk mitigation and adaptation measures in insurance premiums, or by introducing mandatory or quasi-mandatory insurance. Measures to help deepen cat bond markets could also play an important role (**Section 2.2**).

However, climate-related risks are unlikely to be sufficiently insured by the private sector, so additional risk-sharing solutions, such as PPPs, might be needed to provide a backstop to private (re)insurance (**Section 2.3**). In Europe, PPPs already exist in, for example, Spain, France and the United Kingdom. Depending on the design of these schemes, both insurers and reinsurers hold some of the risk alongside government, while policyholders can be incentivised to adapt and reduce risks, thereby reducing moral hazard. This contrasts with the prevailing situation in relation to many catastrophes, where a low private insurance share poses substantial moral hazard since governments, and thus taxpayers, are expected to cover the costs of catastrophes after they have occurred.

Governments can play an additional role in managing financial risks before catastrophes occur. Risk management instruments include disaster reserves, catastrophe funds and cat bonds. But lack of awareness and limited data on catastrophe risks (and on the funds spent on prevention) can hamper the design of risk management strategies. Climate-related fiscal risks are also, so far, largely absent from national fiscal sustainability frameworks. As a consequence, financing generally occurs after the catastrophe through ad hoc reallocations of funds from budgets at local, national and European levels. These potentially large contingent liabilities should be recognised on the balance sheets of fiscal authorities. This would increase the transparency of higher climate-related risks borne by sovereigns and facilitate more structured decision-making on the prudence of accelerating adaptation spending versus bearing costs after catastrophes occur.

The European Commission recently published a new EU strategy on adaptation to climate change, which includes the objective of reducing the insurance protection gap.[1] But a common EU-level approach to disaster risk management is lacking, with legal requirements fragmented across hazards and countries. For less frequent, large-scale catastrophes and weakly correlated hazards, an EU-wide fund that complements national schemes could help to reduce the economic costs of catastrophes by pooling risks and accelerating recovery and reconstruction efforts, while incentivising and promoting risk reduction and adaptation (**Section 2.4**). The fund could be invested in liquid, investment-grade green bonds, thereby also allowing the fund to support complementary efforts to mitigate climate change and reduce global warming. The fund and should have safeguards to tackle moral hazard, such as making access conditional on Member States implementing agreed adaptation strategies and meeting their emissions reduction targets.

The policy options set out in this discussion paper also intersect with and complement wider financial sector policy initiatives (**Section 3**). These include the need to make further progress on the CMU and to consider whether targeted

1 See “EU Adaptation Strategy” on the European Commission’s website.

prudential/macroprudential regulations in the banking sector may be needed to enhance its resilience to the implications of a persistent climate insurance protection gap.

This paper is not intended to reach firm conclusions on specific policies that should be implemented to tackle the climate insurance protection gap. Rather, its aim is to solicit feedback on the possible policy actions set out. The ECB and EIOPA will continue to undertake analysis of these policy options, taking into account the comments received on this paper.

The ECB and EIOPA would welcome comments and feedback on all aspects of this paper. Comments should be sent to this email, ideally by 15 June 2023: ecb_eiopa_staff_protection_gap@eiopa.europa.eu.

1 The economic relevance of the climate insurance protection gap

As climate-related disasters become more frequent and severe, the risk of abrupt economic and financial losses increases. Catastrophe insurance[2] is a key tool to mitigate these losses, but insurance coverage is expected to decrease or become more expensive as a result of climate change.[3] Increased losses from natural disasters linked to climate change could prompt insurers to limit the coverage they offer or charge unaffordable premiums. This could impair the ability of households and firms to finance reconstruction after disasters. It may also pose financial stability risks and reduce credit provision in countries with large financial sector exposures to natural catastrophes. Furthermore, it may further increase the burden on governments, both in terms of macroeconomic risks and in terms of fiscal spending to cover uninsured damage. This section explores these channels and provides evidence of their economic relevance.

1.1 Implications for the macroeconomy

Climate-related extreme events can cause significant economic disruption that may persist over time. Direct aggregate catastrophe losses in the EU amounted to €487 billion in the period between 1980 and 2020.[4] While this implies that the average impact per annum has been limited, i.e. under 0.1% of GDP, this does not necessarily hold for individual years, when losses may be more significant, or at regional level, as lower income countries suffered the highest relative losses (**Chart 2**). The costs of climate-related natural disasters are also expected to rise across EU countries over the course of this century. For example, Gagliardi et al. (2022) estimate that, even in a 1.5°C global warming scenario, related losses across the EU will nearly double by 2050 and triple by the end of the century, with costs being significantly higher under a 2°C or 3°C average temperature increase. In addition, direct losses refer only to the damage caused directly by natural disasters when they occur and in the immediate aftermath.

Catastrophes typically also have an adverse indirect impact on subsequent GDP growth and inflation. This refers to losses related to changes in short and medium-term economic production and consumption owing to, for example, the interruption of

2 Catastrophe insurance is an umbrella term to refer to insurance cover against a wide range of high-severity events, including both natural and human-made disasters. In the context of this discussion paper, catastrophe insurance refers to insurance (private or public) against weather and climate-related natural disasters whose impact is expected to worsen as a result of climate change. It also includes “secondary perils”, i.e. events that occur with higher frequency but with moderate severity and could either occur independently (such as thunderstorms) or as a secondary effect of a major event (such as hurricane-induced precipitation).

3 See IAIS and SIF (2021). Some insurers recently announced their plans to cut natural catastrophe coverage, as the incidence of natural catastrophes exceeds what models have been anticipating. See, for example, InsuranceERM (2023).

4 See EEA (2020).

economic activities or recovery paths. This can affect regional and national GDP growth and consumer price inflation (see Noy, 2009; Felbermayr and Groeschl, 2014; Kousky, 2014; Klomp and Valckx, 2014; Parker, 2018; Botzen et al., 2019; Kahn et al., 2021).

Chart 2

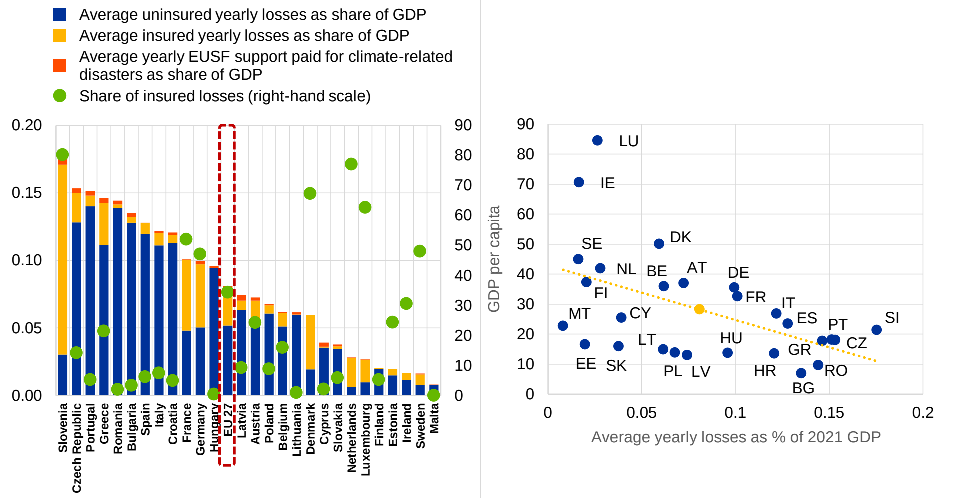
Direct aggregate catastrophe losses may appear limited in the EU, but costs can be sizeable in relative terms for individual years and regions

Insured and uninsured costs of extreme climate-related events

(1980-2021; y-axis left-hand scale: losses as share of GDP, percentages; y-axis right-hand scale: share of insured losses in total losses, percentages)

Costs of extreme climate-related events and GDP per capita

(y-axis: 2021 GDP per capita, EUR; x-axis: average yearly losses as share of 2021 GDP, percentages)



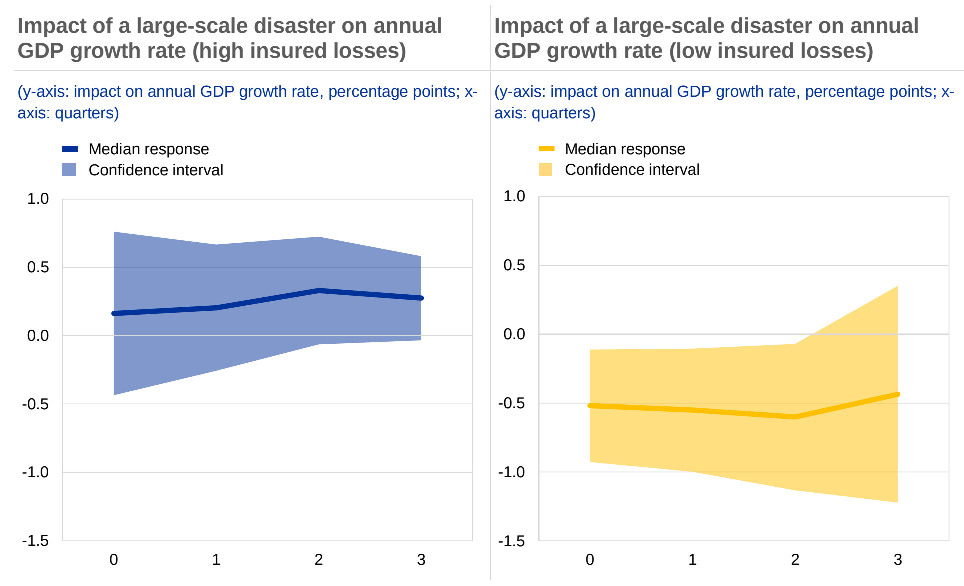
Sources: CATDAT, Eurostat, EUSF data and ECB calculations.
Notes: Both panels include data only on EU countries. Left panel: The figures presented in this chart are based only on CatDat and do not account for PPPs or other factors affecting the share of insured losses. The yearly insured and uninsured losses are calculated as average over the aggregate estimates of losses between 1980 and 2021 included, while EUSF support paid for climate-related disasters is an average between 2002 and 2021. GDP and GDP per capita are dated 2021. There have been no applications for financial support for Denmark and Finland under the EUSF.

Catastrophe insurance plays an important role in mitigating the negative macroeconomic effects of disasters. First, it enables the economy to recover faster by promptly providing the necessary funds for reconstruction and limiting the period of lower output. The overall welfare costs of a disaster depend not just on the severity of the initial damage but also on how swiftly reconstruction can be completed. The reconstruction phase can be prolonged and may even be incomplete in the absence of sufficient resources, potentially leading to supply chain disruptions (Carter et al., 2007; Islam and Winkel, 2017). Insurers' pay-outs reduce uncertainty and support aggregate demand and investment for reconstruction, which helps to accelerate recovery from disasters. Second, catastrophe insurance can increase resilience by improving the understanding and assessment of climate change risks and promoting risk reduction and adaptation measures. Third, it allows the mutualisation of risks and their transfer to private (re)insurance companies, which can provide expertise and incentives for resilience, efficiency and reliability.

Empirical evidence confirms that the impact of disasters on GDP growth depends on insurance coverage (von Peter et al., 2012; Poontirakul et al., 2017; Fache Rousová et al., 2021). For example, a large-scale disaster causing over 0.1% of GDP worth of direct losses can reduce GDP growth by around 0.5 percentage points in the quarter of impact if the share of insured losses is low, i.e. below 35% of the total (**Chart 3**). The adverse effect on GDP growth also persists over the subsequent three quarters. However, if a high share of damages is covered by insurance, the indirect impact on GDP growth may be significantly reduced.

Chart 3

Insurance helps to maintain GDP growth after a natural disaster, while uninsured losses are estimated to have an adverse effect on GDP growth



Sources: EM-DAT, Organisation for Economic Co-operation and Development (OECD) and authors' calculations (taken from Fache Rousová et al., 2021).
Notes: The sample includes 45 countries for which the OECD provides quarterly GDP data from 1996 to 2019. Insured and uninsured losses are imputed for most events where data on total damages are available. The values are imputed on the basis of country-specific regression models, where the dependent variable is the share of insured losses in total damages and the explanatory variables include the log of total damage and dummies for eight different types of disaster (drought, earthquake, extreme temperature, flood, mass movements (e.g. landslides), storms, volcanic activity, wildfire) to the extent applicable for a given country. The charts show the impact of large-scale natural disasters (i.e. with total damage larger than 0.1% of GDP, which represents the third quartile of the loss distribution) when the share of insured losses is high (above the median of 35%) (left panel) and low (i.e. below the median of 35%) (right panel). The estimates are obtained using a panel regression model where the dependent variable is the year-on-year difference in the log of GDP and the explanatory variables include two dummies capturing large-scale disasters with a high and low share of insured losses respectively (included with up to three lags) and country and quarterly fixed effects. For the quarter including the date(s) of the disaster (t=0) and the three subsequent quarters, the y-axis measures the percentage point impact of the disaster on the year-on-year annual growth rate at the end of that quarter. Results are robust to the exclusion of earthquakes and volcanic activity events from the sample, although the significance of the estimates decreases, as earthquakes tend to lead to particularly large damages.

However, as insurance coverage is expected to fall with global warming, the future impact of catastrophes may be greater than similar events in the past. Expected annual damages from climate-related catastrophes in the EU and the United Kingdom are estimated to increase from a baseline of 0.17% of GDP to 0.29% in 2050 if global temperatures increase by 2°C on average by 2050 and there are no adaptation or mitigation measures. With this scale of direct losses, the level of GDP could be 3% lower in 2050 in a scenario of no insurance compared to a scenario of full insurance (Fache Rousová et al., 2021).[5] Economic models which fail to account

[5] These estimates rely on the estimated annual damages from climate-related catastrophes in Feyen et al. (2020) based on different representative concentration pathways (RCPs) and empirical analysis by Fache Rousová et al. (2021).

for this mechanism may underestimate the full magnitude of the macroeconomic costs of climate change.

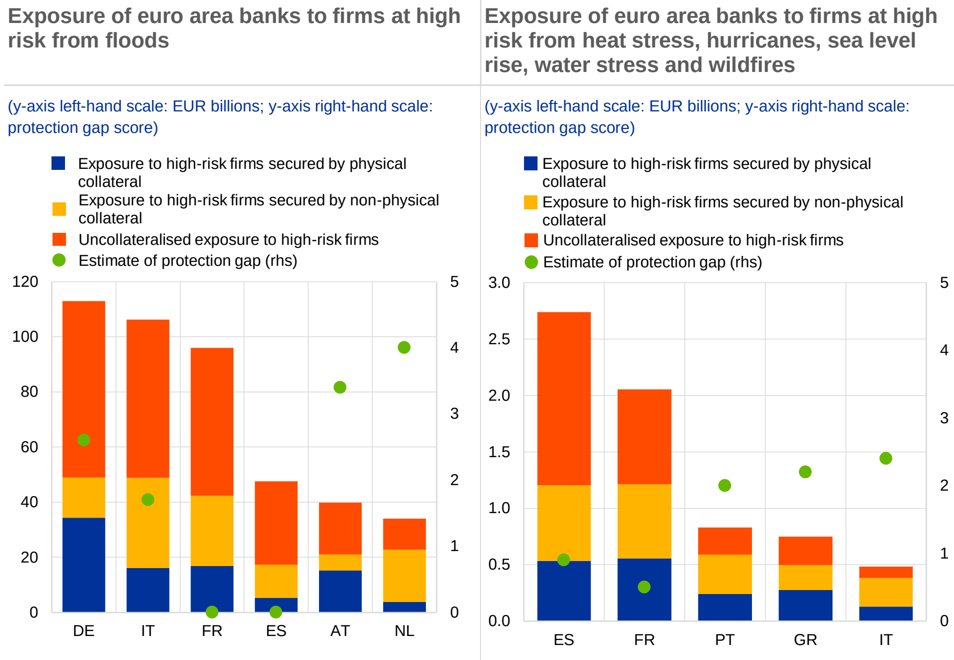
1.2 Implications for the financial system

Natural disasters can be a source of systemic risk for financial institutions and financial markets through two main channels (see Worthington and Valadkhani, 2007; Carney, 2015; IAIS and SIF, 2018; NGFS, 2019; BoE, 2019; FSB, 2020; Alogoskoufis et al., 2021; BCBS, 2021; ECB/ESRB, 2021). First, physical damage of assets can lead to reduced collateral values and/or substantial repricing of loans and securities for financial institutions exposed to high-risk areas. Second, physical risks can lead to supply chain disruptions, which can, in turn, cause large losses for the real economy and on financial institutions' balance sheets. In both cases, a high concentration of key economic activities in high-risk areas can amplify such losses, giving local events wider significance. This can result in a lower provision of credit in high-risk areas and to lower income borrowers, especially from less well-capitalised or less profitable banks (see Garmaise and Moskowitz, 2009; Klomp, 2014; Cortés and Strahan, 2017; Faiella and Natoli, 2018).

Insurance can increase banks' resilience to such shocks by mutualising and transferring collateral and property losses to (re)insurance companies, which are better equipped to manage their climate-related exposures (see ECB/ESRB, 2021; Alogoskoufis et al., 2021). By accelerating reconstruction, insurance can also help to reduce losses from supply chain disruptions. Finally, a lack of insurance may prevent the qualification of some property as eligible collateral, potentially increasing the exposure of banks to credit risk.

Chart 4

The insurance protection gap can increase the exposure of banks to physical risk and reduce the value of collateral



Sources: EIOPA pilot dashboard on insurance protection gap for natural catastrophes, Moody's 427 and ECB calculations (ECB/ESRB, 2022).
Notes: Credit exposures to non-financial corporations (NFCs) above €25,000 are considered; the NFC location used to assign risk levels refers to the head office and the location of subsidiaries of the largest listed firms. Only NFCs domiciled in areas that are classified as high risk, either present or projected, are included. The country breakdown refers to the firm's domicile. The total collateral value at instrument level is capped at the value of the instrument. The protection gap of firms is proxied by the estimate of today's protection gap score of its country and differs across hazards (0 = no risk, 1 = low risk, 2 = low/medium risk, 3 = medium/high risk, 4 = high risk). Left panel: flood risk. Right panel: all other hazards, such as heat stress, hurricanes, sea level rise, water stress and wildfires.

Around 75% of the exposures of euro area banks to firms subject to high or increasing flood risk is uncollateralised or secured by physical collateral that is also exposed to physical risk, i.e. €370 billion (**Chart 4, left panel**). This raises concerns, especially in countries with a large insurance protection gap. The potential losses for banks exposed to high-risk firms (or households) would be significant should extreme floods intensify or hit a large share of those who are vulnerable. The exposure of euro area banks to firms subject to other climate-related hazards – such as heat stress, hurricanes, sea level rise, water stress and wildfires – is much lower, but it is also mostly uncollateralised or secured by vulnerable physical collateral (**Chart 4, right panel**).

1.3 Fiscal implications

Catastrophe risks can adversely affect a country's public finances and debt sustainability due to: (i) higher fiscal costs following disasters, for example from higher social assistance expenditures and relief payments, and lower tax revenues; (ii) investment needs for adaptation and risk mitigation; and (iii) direct losses on government assets, which can all affect credit quality and debt financing rates (Zenios, 2022). These costs may cause deviations in fiscal outcomes from those that were forecast (Gamper et al., 2017). A recent analysis by Gagliardi et al. (2022), which simulates the fiscal shocks of natural disasters in 13 EU countries, projects debt-to-GDP ratios to be on average 2.3 and 2.7 percentage points higher by 2032 in 1.5°C and 2°C global warming scenarios respectively.[6] Pressures on fiscal expenditures may also arise in periods of generally lower growth following disasters, as capital is typically absorbed by reconstruction activities rather than new investments. Lower economic growth also reduces government tax revenues. The scale of contingent fiscal liabilities from growing climate-related catastrophes – which are potential liabilities that materialise if catastrophes occur – therefore increases the need for well-designed disaster risk management tools and risk-sharing/transfer mechanisms that can enhance resilience.

Chart 5

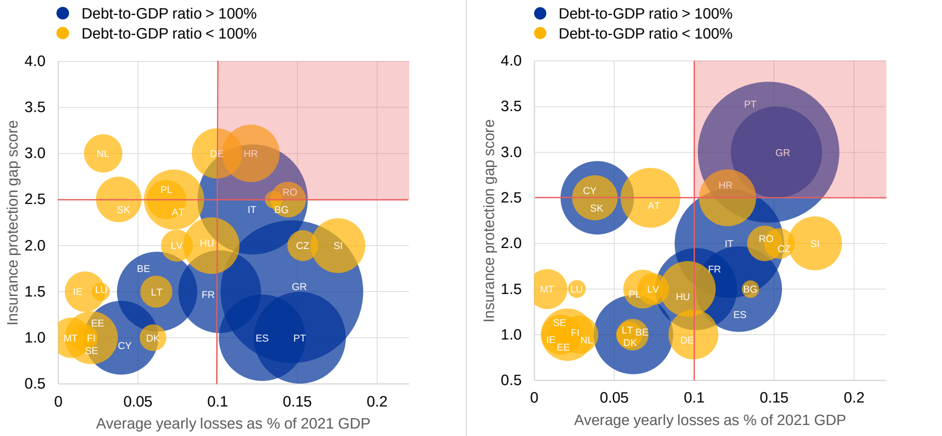
Some countries suffering historically high catastrophe losses as a share of GDP also have a large insurance protection gap, which can weigh on debt sustainability

Historical losses and protection gap for floods

(x-axis: average yearly losses (1980-2021), percentages of 2021 GDP; y-axis: protection gap score; bubble size: government debt, percentages of 2021 GDP)

Historical losses and protection gap for wildfires

(x-axis: average yearly losses (1980-2021), percentages of 2021 GDP; y-axis: protection gap score; bubble size: government debt, percentages of 2021 GDP)



Sources: EIOPA dashboard on insurance protection gap for natural catastrophes, EEA, Eurostat, ECB GFS and ECB calculations.
Notes: The x-axes refer to the average yearly losses (data from the EEA) from floods and wildfires respectively between 1980 and 2021 relative to GDP (data from Eurostat). The size of the bubble is proportional to the country's debt-to-GDP ratio. The y-axes refer to EIOPA's estimated protection gap score, ranging from 0 to 4 (0 = no gap, 1 = low, 2 = medium, 3 = high, 4 = very high). Each protection gap score is country and peril-specific. The red shaded areas indicate countries with both a high protection gap and high average losses, the thresholds for which are set at a protection gap score of 2.5 out of 4 and 0.1% of GDP respectively.

In this context, insurance coverage can help to mitigate fiscal pressures from disasters, especially for countries with high physical risk (Melecky and Raddatz, 2011). When most losses are uninsured, governments typically finance recovery and reconstruction activities, which increases sovereigns' gross financing needs or leads to a sub-optimal allocation of public funds.[7] Expectations of such unconditional government support after disasters can also create moral hazard and lower

6 See European Commission (2022).

7 In 2021, summer floods hit central European countries causing damages totalling €46 billion, of which only €11 billion was insured. Germany responded by committing up to €30 billion to fund reconstruction efforts (see Federal Ministry of Finance, 2021).

incentives for households and firms to adapt and reduce their vulnerability to climate-related catastrophe risks, thereby worsening the losses suffered during disasters.

Climate-related catastrophes are also likely to have asymmetric effects on the fiscal stability of European countries, as economies differ significantly in their climate risk exposures, vulnerabilities and resilience. Some countries suffering high historical losses from disasters (relative to GDP) also exhibit a large insurance protection gap (red shaded areas in **Chart 5**). Among these countries, some have a high debt-to-GDP ratio, which can reduce their fiscal space to respond to disasters in the absence of well-designed risk management tools.

2 Potential policy measures to reduce the climate insurance protection gap – the ladder approach

In light of the negative economic implications of the climate insurance protection gap, this section explores potential policy measures to tackle this gap and mitigate catastrophe risks from climate change by means of enhanced insurance coverage and adaptation measures. These measures are designed, as a minimum, to:

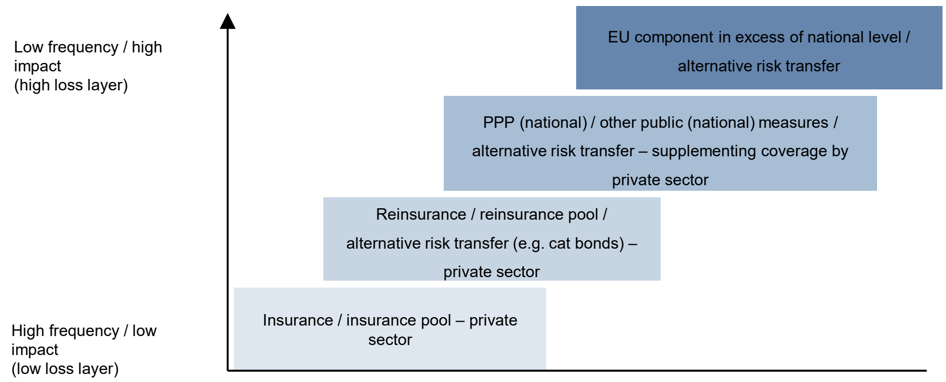
- help to provide prompt insurance claim pay-outs in the aftermath of a natural disaster;
- incentivise risk mitigation and adaptation measures;
- be complementary to existing insurance coverage mechanisms;
- require the sharing of costs and responsibilities across the relevant stakeholders to ensure "skin in the game" and reduce moral hazard;
- lower the share of economic losses from major natural disasters borne by the public sector over the long term.

While it is important to increase insurance coverage from current levels, this may not be sufficient to tackle the protection gap sustainably. As climate change is expected to increase the frequency and severity of extreme events, insurance coverage will probably continue to become more expensive and/or less available. An increase in insurance should therefore happen in tandem with measures that can help mitigate the underlying risks, especially as some risks might prove to be uninsurable.

This discussion paper uses the term "ladder approach" in the context of indicating the share of losses from natural disasters borne by various parties at different loss layers (**Figure 1**).

Figure 1

The ladder approach to catastrophe insurance



Source: Authors.

Primary insurers who sell policies to individuals and businesses tend to operate in low to moderate loss layers that are characterised by relatively high-frequency, low-impact events. They are typically either unable or unwilling to bear the full magnitude of losses from low-frequency, high-impact events such as natural disasters[8] (high loss layer). They cede residual risks from these types of events to reinsurers, who operate in a global reinsurance market to diversify across geographies and achieve economies of scale. Additionally, some reinsurers buy reinsurance from other reinsurers (retrocession), which provides further diversification. Alternative risk transfer mechanisms such as cat bonds are also used to spread the residual risks to a broader set of capital market investors.

However, modelling and insuring losses becomes more challenging, even for reinsurers, in the case of extreme events that are very rare but can cause very substantial economic damage when they occur. At such very high loss layers, the traditional model of reinsurance starts to reach its limits, causing reinsurers to either charge very high premiums or stop underwriting catastrophe risks altogether ("hard market"). This has a knock-on effect on primary insurers and policyholders – they must either pay a very high premium or bear the risk themselves (retention). As such, climate-related risks may not be sufficiently insured by the private sector, and this problem is expected to worsen with global warming. Public sector intervention may then become necessary to supplement the insurance provided by the private sector.

The ladder approach builds on the existing frameworks of private insurance and public sector intervention at the national level. It is aimed at making the private sector more resilient to climate-related catastrophes. PPPs at the national level can play an important role by facilitating and incentivising risk mitigation and adaptation measures, while promoting broad-based insurance coverage. The ladder approach

8 Property insurance contracts in Europe are often multi-risk and cover all or a subset of weather-related perils (EIOPA, 2022). Actual coverage and market practices differ between countries, including within Europe. For instance, in some countries, storm/hail, flood and/or wildfire coverage may be included in property insurance contracts by market practice or by law, while in others this may not be the case. In addition, insurance policies can offer insurance protection for all or only a subset of property-related losses (i.e. building, content and business interruption-related losses).

also makes the case for possible coordination of public sector efforts at the EU level in order to manage the residual risks in excess of planned capacity at the national level. The purpose of these approaches is not to provide unconditional taxpayer-funded financial guarantees for uninsured losses but to enhance efficiency in the way public funds are used and reduce moral hazard relative to the typical status quo of unconditional and sometimes poorly targeted government support after disasters. Over time, this should help ensure that private insurance markets continue to function in an orderly manner in the face of climate change induced risks and reduce the need for government financial intervention. Ex ante clarity from the government about its role in compensation of damage is important for private insurance markets to be effective. Moreover, increased insurance uptake and more resilient private insurance markets should translate into a lower share of economic losses borne by the public sector.

2.1 Layer 1: Low to moderate loss layers: potential measures to enhance private insurance and impact underwriting

While further insurance penetration is beneficial and desirable, insurance provision should be carefully designed to ensure that it encourages adaptation and reduces vulnerability to climate-related catastrophes over time. Insurers should provide incentives for risk reduction and adaptation by, for example, promoting risk awareness and providing risk-based incentives linked to premiums (see Linnerooth-Bayer et al., 2019). Enhanced coordination between the public and private sectors in relation to risk assessment practices and standards would also be helpful. While directly reducing preventable damages from catastrophes and increasing resilience, such measures would also support insurability and help to limit the risk of a widening insurance protection gap.

Impact underwriting is an underwriting and pricing strategy aimed at incentivising the policyholder to implement ex ante (structural) measures and reduce exposure to climate-related hazards.[9] The price of insurance and the contractual terms and conditions under which insurance is offered are strong signals of the level of risk. Therefore, risk-based incentives linked to premiums help enhance the awareness of policyholders of current vulnerabilities. And premium discounts can provide incentives to implement adaptation and mitigation measures that minimise physical risk exposure to climate-related hazards. For example, premium reductions could be associated with homes meeting certain standards with respect to flood-proofing in flood-prone areas or protection against storms, and with the use of real-time weather data and alert systems in relation to crop insurance. The cost of implementing the risk reduction measure could be compensated by a lower premium.

Integration of climate adaptation measures in insurance products requires not only innovative product design but also coordination between insurers and public authorities. For example, standardisation of risk assessment practices can help in the recognition of adaptation measures in insurance contracts. Similar approaches

9 See EIOPA (2021a).

exist in the US insurance market, for instance on the basis of the FORTIFIED programme of the Insurance Institute for Business and Home Safety (IBHS), which provides recommendations on climate-related risk prevention measures related to wind, hail and wildfire risks.[10] In the US, the National Flood Insurance Program (NFIP) offers lower premiums when flood mitigation measures are in place, and in some states policyholders can obtain premium discounts on their property insurance if the property meets certain standards.

Affordability and accessibility alone may not be sufficient to ensure high levels of private insurance coverage against catastrophes. Behavioural traits, information availability and the way insurance is sold significantly influence consumer demand for insurance. In particular, a lack of policyholder awareness about climate change and related adaptation measures is a key factor influencing the demand for corresponding insurance products.[11] Climate-related risk awareness could be raised by, for example, dedicated information campaigns targeted at individual policyholders, ideally incorporating granular information about the effects of climate change on the policyholder's risk exposure at a local level. Information campaigns or web-based tools could also be used to raise awareness about adaptation measures and their potential effectiveness in risk reduction.

2.2 Layer 2: Higher loss layers: potential measures relating to reinsurance and catastrophe bonds

Reinsurance

Reinsurance plays a key role in managing risk from low-frequency, substantial-impact events such as hurricanes, wildfires and major floods ("high loss layer"). Diversifying such risks becomes progressively more challenging at higher loss layers. Large reinsurers often diversify across geographies and exploit economies of scale to access and utilise capital more efficiently. Some reinsurers purchase their own insurance from other reinsurers (retrocession). Bilateral agreements between (re)insurers can become extremely complex, involving a combination of various types of reinsurance (e.g. proportional vs non-proportional).[12]

One criticism of the non-life insurance and reinsurance industry is that the contracts for risks such as catastrophe risk (and other non-life risks in general) are structured and priced annually. While this feature shields (re)insurers from the effects of material mispricing of risk, it also does little to encourage the incorporation of climate change considerations into the design and pricing of reinsurance because there is always the "short cut" of adjusting the premium after one year. Long-term insurance contracts, which provide a guaranteed price (or guaranteed ceiling and floor price) over a term from 3 to as much as 25 years, could significantly foster adaptation by

[10] See "FORTIFIED Solutions", IBHS and "Regulatory Framework for FORTIFIED Insurance Incentives", IBHS.

[11] See EIOPA (2023).

[12] Proportional reinsurance involves compensation to the reinsured in proportion to their losses, whereas non-proportional reinsurance, such as stop-loss reinsurance, compensates the reinsured beyond a specified level of loss (but up to a limit).

providing greater incentives for the insured to invest in cost-effective property-level resistance and resilience measures (Maynard and Ranger, 2012). In practice, however, there are potential trade-offs associated with multi-year non-life insurance contracts.[13] Such contracts could decrease flexibility and choice for customers, because customers would not easily be able to renegotiate contracts or switch to an alternative (re)insurer. They may also increase the risk of insolvency of (re)insurers and add to the complexity of catastrophe risk modelling. Without the possibility to reprice the contracts annually, (re-)insurers are likely to charge higher premiums at the outset to absorb such risks.

Alternative risk transfer – catastrophe bonds

The chain of risk transfer from insurers to reinsurers helps to improve insurability in high-risk areas and reduce the volatility of insurance pay-outs. However, at the highest loss layers, the cost of capital required to cover the exposure may simply become uneconomical for private institutions. Cummins and Trainar (2009) argue that for such risks, issuing equity shares may not be the best way to access the capital markets. This is where alternative risk transfer mechanisms such as insurance-linked securities (ILS) can be useful.

(Re)insurers often use alternative risk transfer mechanisms that tap capital from sources other than the company shareholders (traditional reinsurance) to bolster their risk-bearing capacity. Cat bonds are a type of ILS that transfers insurance risk to capital market investors. (Re)insurers typically use cat bonds to manage exposure to very low probability, high-impact events. Investors put up capital when buying these securities and bear the insurance risk in exchange for a coupon. If the covered event occurs, investors stand to lose all or part of the amount paid upfront. Like other forms of securitisation, such as mortgage-backed securities (MBS) that pool mortgage loans in a special purpose vehicle (SPV), a cat bond also pools investors' capital in an SPV. While the income paid to investors from an MBS is linked to the credit risk of the mortgage borrowers, in the case of a cat bond it is linked to the modelled expected loss from the insured event. A given issuance of a cat bond can have multiple tranches, each with a different level of expected loss and corresponding income level for investors. The counterparty default risk in a typical cat bond transaction is virtually zero, because the paid-up capital is held in a secure collateral account. This contrasts with a traditional reinsurance contract, which carries the risk that the reinsurer might be unable to pay claims if the insured risk materialises in the future.

Cat bonds offer several benefits to both investors and (re)insurers. They allow catastrophe risk to be transferred to a wider set of investors, thereby diversifying (re)insurers' sources of capital. Unlike traditional non-life insurance, cat bonds are typically structured to provide cover over multiple years, which can help to deliver some of the benefits mentioned above. Using a combination of traditional reinsurance and cat bonds can also lower the overall cost of coverage for (re)insurers, as higher loss layers are likely to be more expensive to reinsure through traditional reinsurance alone (Trottier and Lai, 2017). This is because when the

---

13 See EIOPA (2021a).

magnitude of potential losses and the correlation among risks increases, the cost to the sponsor of holding an adequate amount of capital (or buying reinsurance) to cover the catastrophe exposure may be higher than the premium demanded by investors in cat bonds (Cummins and Trainar, 2009).[14]

Investors in cat bonds benefit from low correlation with equity and credit markets. As such, cat bonds can provide useful diversification, particularly during episodes of crisis and high market volatility (Demers-Belanger and Lai, 2020). Investors in the environmental, social and governance (ESG) space are also turning to cat bonds as an instrument for impact investment – an investment strategy aimed at generating social or environmental benefits while delivering financial gains. For example, investors in cat bonds intermediated by the World Bank to enhance resilience against natural disasters in lower income countries include pension funds, insurers and other institutional asset managers. Furthermore, collateralised assets from several cat bonds have been invested in green initiatives. Cat bonds can therefore potentially combine impact underwriting with impact investment. **Box 1** discusses further details about the market that help to motivate potential policy measures.

On the other hand, capital market investors can be opportunistic about buying cat bonds and may not be a reliable source of capital over the long term. Certain conditions could trigger a sudden retreat of investors. These include an increase in interest rates, which would diminish search-for-yield behaviour, underestimation of underlying risks by either party or any situation that is not favourable to a “quick-entry, quick-exit” model. By contrast, traditional reinsurers, who typically place more emphasis on relationships with their counterparties, are more likely to keep providing reinsurance capacity across market cycles. Furthermore, the success of cat bonds as an asset class relies on well-functioning securitisation arrangements and linkages with financial market participants outside the (re)insurance sector. These linkages can be a potential vulnerability in times of financial market distress.

Box 1
A closer look at the cat bond market

Despite the potential benefits for both (re)insurers and investors, cat bonds are not an easy substitute for traditional reinsurance, especially in Europe. The market for cat bonds started to develop in the mid-1990s in the aftermath of Hurricane Andrew (1992). That period witnessed a decline in the supply of reinsurance and an increase in premiums – conditions referred to as a “hard market”. High insured losses compelled (re)insurers to re-examine their catastrophe risk exposures and consider alternative forms of reinsurance, including cat bonds. Subsequent hard markets in 2002 and 2006, following the 9/11 attacks and hurricanes Katrina, Rita and Wilma respectively, also saw increased issuances of cat bonds. The market has continued to grow materially in terms of size and the variety of risks covered, but has remained largely dominated by issuances covering US-based perils. To put the market size in perspective, cat bonds had USD 35.5 billion in capital outstanding at the end of 2022, compared to USD 467 billion in traditional reinsurance capital at the end of August 2022.

[14] The “sponsor” is the party that cedes the insurance risk. This is different from the SPV, which is set up by or on behalf of the sponsor and is the issuer of a cat bond.

The process of issuing a cat bond involves obtaining an independent assessment of the risks being covered by the bond. This is important for investors because it mitigates the concern that the sponsor will underwrite excessive risk or have better information on the risk. A positive externality of this process is easier access to pricing and risk data for industry outsiders, who can analyse such data to obtain insights into catastrophe risk pricing. In the traditional reinsurance market, this information is only available to market participants such as underwriters and brokers. This process also means that the risks that have better coverage by risk modelling service providers and represent sizeable insurance markets around the world (e.g. US windstorms, US earthquakes and Japanese earthquakes) tend to feature most prominently in cat bond transactions. European perils still represent a relatively small portion of bonds currently outstanding. Part of the reason for this lies in the high transaction costs involved in executing a cat bond transaction, which inter alia involves setting up a special purpose vehicle (SPV), hiring an independent risk modelling agent and marketing securities.

In recent years, several bonds covering catastrophe risks in certain lower-income countries have been placed successfully in the market. These bonds are intermediated by the World Bank, which leverages its expertise to make the reinsurance and capital markets accessible to countries with limited direct access to insurance. Strikingly, World Bank intermediated cat bonds have been priced more favourably (for sponsors) than other outstanding cat bonds – meaning that issuers had to pay a lower reinsurance premium per unit of expected loss.[15] Since these bonds cover risks in less-developed countries with more limited access to international reinsurance markets, this seems contradictory to the notion of well-modelled risks in large insurance markets dominating the cat bond market. There are several reasons for this:

- The perils covered by World Bank cat bonds are exotic (i.e. not the typical ones which are dominated by US perils) and therefore provide even more diversification to investors than other cat bonds.

- World Bank cat bonds are mostly parametric – meaning that pay-outs are triggered on the basis of a parameter reaching a threshold value (e.g. windspeed in a windstorm), irrespective of the actual damage caused. Such instruments require less expertise in determining the claims pay-out compared to indemnity triggers. They also reduce the chances of investors' capital being "trapped" for prolonged periods due to disputes between the (re)insurer and the (re)insured. Parametric insurance, however, may not have the intended benefit if a substantial loss event occurs while the parameter thresholds for triggering pay-outs are marginally missed.

- Repeated transactions over time with consistent terms and conditions can lower issuance costs and make it easier for investors to assess the risk-reward balance. An experienced issuer that is well recognised in the market may be able to influence the issuance spread in its favour.

While this discussion illustrates how the various characteristics of a cat bond may be customised to strike an equilibrium between the preferences of the sponsor and the investor, it also underscores its role as a risk transfer mechanism that is complementary to, and not a substitute for, traditional (re)insurance.

[15] See Financial Protection Forum (2021).

Potential measures for greater and more effective use of cat bonds in both the private and public sector

Policy measures could be undertaken at both national and EU level to foster greater and more effective use of cat bond markets in both the private and public sector, thereby helping to reduce the climate insurance protection gap.

Issuing a cat bond in Europe is currently expensive and the process of setting up an ILS vehicle is more cumbersome than in some non-European jurisdictions. Despite the higher issuance costs, some well-known (re)insurers in the EU/European Economic Area have, however, chosen to issue cat bonds via SPVs domiciled in Ireland, thereby benefitting from being in a Solvency II jurisdiction. Among other things, this simplifies the calculation and reporting of capital requirements for Solvency II (re)insurers.

Public authorities in the EU could consider measures that help to foster a more vibrant cat bond market for the private sector. Some governments outside the EU have already taken concrete steps to attract issuers of cat bonds to their jurisdictions. For example, in 2021 the Bermuda Monetary Authority (BMA) amended the licensing and registration process for entities looking to issue ILS such that it can be completed within three business days.[16] In 2021 the Insurance Authority of Hong Kong announced a two-year pilot scheme to incentivise insurance companies to issue ILS in Hong Kong.[17] Among other things, the Hong Kong scheme offers a grant to cover the upfront issuance costs for eligible ILS. Similarly, in 2021 the Monetary Authority of Singapore (MAS) announced a grant scheme covering issuance costs for qualifying ILS.[18]

Cat bond issuance by the public sector has been increasing over time, along with the number of countries that participate in issuance.[19] A prominent example is the California Earthquake Authority (CEA), a local state agency that underwrites residential earthquake risks in the United States and has established itself as a well-recognised issuer in the cat bond market. As discussed further in **Section 2.3**, PPPs may be able to pool residual risks at higher loss layers more efficiently than the private sector. They may then be able to securitise part of this pool in the form of cat bonds. While a cat bond issued by a national PPP would typically cover risks that are limited geographically to the Member State concerned, a platform at the EU level could be used to identify securitisation opportunities to pool residual risks from multiple national PPPs. This could be made possible by improving the exchange of information on catastrophe risks and combining expertise on underwriting and placement of securities at the EU level. Evidence from World Bank intermediated cat bonds (see **Box 1**) also suggests that multi-country cat bonds issued on a repeated basis would probably benefit from, among other things, lower overall operational and issuance costs relative to individual single-country issuances. Over time, data on catastrophe modelling and the pricing of risks gathered as part of issuing cat bonds

---

16 See BMA (2021).

17 See Insurance Authority of Hong Kong (2021).

18 See MAS (2021).

19 See Ando et al. (2022).

could also help to drive efficiencies in future issuances and inform policymaking on natural disaster risk financing at the national and European level.

Cat bonds issued by the public sector at the national level could also serve as an investment option for funds pooled as part of any EU-level measures (see **Section 2.4**), provided they meet the criteria for these funds. If and when such a bond is triggered following a major natural disaster, the principal amount could be made available for pay-out promptly. Otherwise, the investment earns a coupon. The overall market for cat bonds would also benefit from such transactions.

2.3 Layer 3: National measures – the role of the public sector

2.3.1 Public disaster risk management measures

Given the potentially significant macroeconomic, financial stability and welfare consequences of natural disasters, especially when insurance coverage is limited, there is a two-fold role for public sector intervention. First, the public sector can contribute to decreasing the insurance gap by helping to enhance private (re)insurance coverage beyond current levels. Second, the public sector can prepare itself better for the risks stemming from the uninsurable part of the insurance gap. Both roles may become increasingly important as global warming leads to more frequent and severe climate-related catastrophes, and the approach of the public sector to managing disaster risk can be crucial in influencing resilience.

Currently, public support is often provided via emergency relief agreed after a disaster has struck. Governments typically increase taxes, reallocate funds from other budgeted activities and/or issue bonds to raise the financial resources that are needed to repair public infrastructure and support affected households and firms.[20] Such ex post government relief can create uncertainty for households and firms who may be unsure about when or whether they will receive support, with possible adverse macroeconomic consequences. Since it is typically unconditional, such relief can also create moral hazard as it does not provide incentives to households and firms to adapt and reduce their vulnerability to catastrophe risks.

The public sector can prepare for these contingent liabilities by enhancing its ex ante disaster risk management strategy. This can include supporting ex ante contingent financing and risk transfer by, for example, creating national reserve funds, working with the private sector to establish public-private insurance schemes that pool and diversify risks (see **Section 2.3.2**) or exploiting capital market products that transfer part of the risk to investors. Such approaches can ensure timelier, more certain access to funding after disasters. In addition, they may be more efficient and better targeted than ex post disaster relief if they foster and leverage strong cooperation with the private (re)insurance sector, thereby potentially also helping to address and

---

[20] In some cases, particularly in less-developed countries, the international community provides assistance through specific loans and aid (e.g. from the World Bank). In the EU, countries can also apply to the EUSF for grant funding after natural disasters, as discussed further in Section 3.4.

limit the distributional impact of catastrophes within countries. They may also increase incentives for firms and households to adapt, by requiring gradual risk reduction and adaptation measures that would help lower prospective losses when a disaster strikes, thereby also limiting moral hazard (see Box 2). As such, ex ante public sector disaster financing approaches may be able to provide timelier, more efficient relief for the same, or possibly even lower, fiscal share in the total outlay compared to continuing with the status quo.

From a fiscal perspective, the choice between ex ante and ex post instruments also involves a trade-off between providing one-off fiscal support after a disaster has struck, which has a sudden impact on public finances, and providing or subsidising insurance, which entails upfront investment. The magnitude of ex post fiscal support depends on the costs of catastrophes. In Europe, in the past these costs have typically been small relative to GDP, but with heterogeneity across countries and years (see **Section 1.1**). More severe catastrophes in the future could have the potential to affect some countries' solvency and liquidity abruptly, with possible implications for the accessibility and cost of sovereign financing.

Fiscal authorities should plan for the contingent liabilities related to the physical risks from climate change (OECD, 2017 and 2021).[21] To help governments gauge the possible future budgetary risks from climate change, the scenarios used for debt sustainability analysis (DSA) in the EU should be augmented to include climate risks and to reflect macroeconomic projections that consider region-specific physical risks, as also highlighted by the European Commission (2022).[22] According to these stylised stress tests, for selected EU Member States and in the context of the European Commission's standard DSA risk framework, there is a need to adopt mitigation and adaptation policies, including insurance and climate-resilient debt instruments, to boost countries' financial resilience to climate change and dampen the potential fiscal impact of climate-related events in the long term.

More generally, countries should develop their fiscal frameworks to identify and account for the costs of natural disasters, adaptation and mitigation in order to make informed trade-offs. This requires better information and data and improved governance and management of climate risks.[23] Pro-active measures on the vulnerability of buildings, planning rules that determine the location of exposures and climate change-resilient public investments are also likely to be important elements of a resilient society. This may also include (potentially highly contentious) discussions about managed retreat from particularly exposed areas.

---

21 See, for example, Aligishiev et al. (2022).

22 For a conceptual framework on how to include climate change effects on growth and public finances in public debt sustainability analysis, see European Commission (2020a).

23 Initiatives to improve climate-related governance standards include the Task Force on Climate-related Financial Disclosures, which is supported by many companies and central banks, but only a few EU Member States. The Inter-American Development bank has developed an Index of Governance and Public Policy in Disaster Risk Management for Latin American countries.

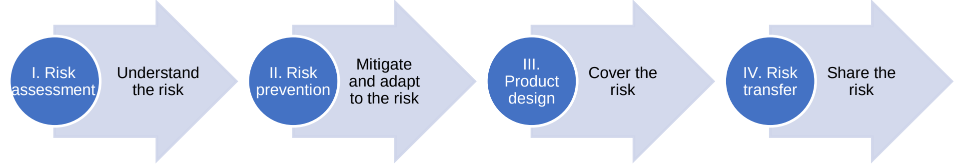
2.3.2 Public-private partnerships

PPPs are insurance schemes which provide government financial support that supplements the losses insured by the private sector. They can support the overall functioning of the insurance market by providing additional coverage either via direct insurance or by indemnifying a private (re)insurer against extraordinary events.

PPPs are already in place in some European countries to manage particular disaster risks (see **Table 1**). For example, Caisse Centrale de Réassurance (CCR) in France provides reinsurance for natural disaster-related risks. The coverage must be included in all property insurance policies. But to be eligible for compensation via the scheme, the damage must be covered by private property insurance to begin with. Thus the scheme relies on the insurance industry network to ensure widespread coverage. Similarly, Consorcio de Compensación de Seguros (CCS) in Spain provides cover for catastrophe risks which is mandatorily linked to the valid taking out of an insurance policy (typically from private insurers) in certain lines of business. Such mandatory inclusion of catastrophe risks is often a key element of public and/or PPP insurance schemes.

Mandatory insurance coverage, which is the requirement for everyone to insure against catastrophes, and/or the mandatory offer of cover, which is a requirement for insurers to offer catastrophe cover alongside, for example, property insurance, entails certain trade-offs. It can help to improve insurability in high-risk areas via mutualisation. Limiting the scope of coverage may lead to the very gaps that such a scheme aims to address. On the other hand, mandatory insurance schemes supported by the public sector may turn out to be regressive and end up subsidising development in hazardous locations and increasing residual risk (Owen and Noy, 2019) (see **Box 2**). In addition, without appropriate safeguards, improved affordability of catastrophe insurance may disincentivise risk reduction and adaptation measures. For example, the National Flood Insurance Program (NFIP) in the United States requires properties in high-risk flood areas to have flood insurance for mortgages from government-backed lenders. Until 2021 the NFIP charged the same amount for insurance, regardless of the value of the property and the share already insured privately. The Federal Emergency Management Agency (FEMA) then adjusted this mechanism to ensure that insurance prices reflected risks at the individual building level, thereby strengthening incentives for risk reduction.

Figure 2
Elements of a shared resilience solution



Source: EIOPA (2020).

The design of PPPs should consider the four elements of a shared resilience solution: (i) risk assessment, (ii) risk prevention, (iii) product design and (iv) risk transfer (**Figure 2**).[24] This implies that certain steps should be considered before deciding on the specifics of risk-sharing arrangements. First and foremost, a sound understanding must be developed of the underlying risks, for instance via enhanced sharing of information on catastrophe risk modelling. Second, pro-active measures for risk mitigation and adaptation should be preconditions for public sector involvement. Third, the insurance products should be designed in a manner that is easy for the policyholder to understand and provide the appropriate coverage at an affordable premium.

As such, PPPs should do more than just provide a financial backstop. They should ensure that the costs and responsibilities associated with having a resilient catastrophe insurance coverage programme are shared between the public and private sectors, with "skin in the game" retained for the latter. Furthermore, policyholders should also retain part of the risk to mitigate moral hazard, or could alternatively be offered reduced premiums in return for implementing risk mitigation measures.

Table 1
Indicative classification of natural catastrophe insurance arrangements in European countries

National property insurance schemes covering residential and commercial assets for coastal floods, river floods, wildfires and windstorms

	Voluntary private market	Semi-voluntary private market	Mandatory private market	Semi-voluntary PPP market	Mandatory PPP market
Premium type	Risk-based	Flat Risk-based	Flat	Flat Risk-based	Flat
Insurance coverage	Voluntary	Voluntary	Mandatory	Voluntary	Mandatory
Mortgage insurance coverage	Voluntary	Mandatory (by banks)	Mandatory (by law)	Mandatory (by banks)	Mandatory (by banks)
Present in…	Austria, Italy, Finland	Most EU countries (across central, southern, and eastern Europe)	Liechtenstein	Spain, Denmark	France

Sources: EIOPA dashboard on insurance protection gap for natural catastrophes and ECB calculations.
Notes: "Risk-based premiums" reflect the insured risk, while "flat premiums" refer to premiums set as a fixed percentage of the total value insured (see the Technical Description of the EIOPA dashboard on insurance protection gap for natural catastrophes). Schemes covered are for both commercial and residential assets and for coastal floods, river floods, wildfires and windstorms. An initial division into insurance scheme clusters was obtained by running k-means cluster analysis on a sample of 157 national schemes and related information retrieved from EIOPA's dashboard. To allow such analysis, only national schemes without any missing information for any of the categories were considered, thus reducing the initial sample of 224 schemes (as included in the dashboard) to 157. Only EU countries' national schemes were included in the analysis, plus Liechtenstein to provide an example of the mandatory private market category. In the dashboard, each national scheme is specified by country (EU Member States plus Liechtenstein), by each of the four perils and by type of asset (commercial or residential) – obtaining a matrix of 28 x 4 x 2. Inspired by Tesselaar et al. (2020).

[24] See EIOPA (2020).

2.4 Layer 4: EU-level measures

A possible European insurance component

Approaches to disaster risk management vary significantly across EU countries (**Table 1**). This partly reflects the varying geographical and climatological characteristics of Member States, which leaves them exposed to different climate-related perils (e.g. coastal floods, river floods, wildfires and windstorms). This leads to a historically weak cross-country correlation of large climate-related disasters, which rarely affect multiple EU countries at the same time.

Given this, there may be diversification and risk pooling benefits that could be exploited at the EU level, especially in relation to very large disasters. In particular, a strengthened European fiscal component for natural disaster relief could complement national insurance schemes by making financial assistance for reconstruction available to Member States following large, infrequent disasters. Such an approach could help to close the climate insurance protection gap further, while also providing incentives for Member States to enhance national insurance coverage and pursue risk mitigation, including adaptation and mitigation measures. By helping to tilt the scales further towards ex ante disaster risk solutions, an EU-wide scheme could even reduce the overall share of expenditure in relation to climate-related catastrophes borne by the public sector compared to the status quo of mostly national-level emergency post-disaster relief.

The EU currently provides only limited disaster relief, which is not specific to climate-related events, in the form of the EUSF. Member States can request some financial assistance for emergency relief and reconstruction from the EUSF for non-insured damages following major disasters[25], but pay-outs are small compared to the overall costs of such events. Initial pay-outs following a disaster are capped at 25% of the total envisaged contribution and may not exceed €100 million per Member State. Between 2002 and 2021, the EUSF has, on average, covered 15% of the costs of eligible emergency operations[26] and 3% of total direct damages across all covered disasters. The EUSF's current annual budget is around €500 million, which can be carried over if unused or advanced if exhausted, but it fell under the 2021-2027 multiannual budget agreement, even though the EUSF's scope was simultaneously broadened to cover public health emergencies.[27] This makes it difficult for the EUSF to meet current demands,[28] especially given recent large climate-related catastrophe costs incurred by several European countries. For example, the summer 2021 flood disaster cost Germany alone more than €40 billion, adding to the €35 billion already borne by the country after the 2018 and 2019 summer heatwaves and droughts (see Prognos, 2022). This imbalance between demand and maximum pay-out of the EUSF is likely to become even more evident as the frequency and severity of

---

25 Major disasters are defined as disasters incurring direct damage above €3 billion in 2011 prices, or 0.6% of gross national income (GNI), or 1.5% of a NUTS 2 region's GNI. See Council Regulation (EC) No 2012/2002 of 11 November 2002 establishing the European Union Solidarity Fund (OJ L 311, 14.11.2002, p. 3).

26 Determined under Council Regulation (EC) No 2012/2002.

27 See European Commission (2023).

28 ibid.

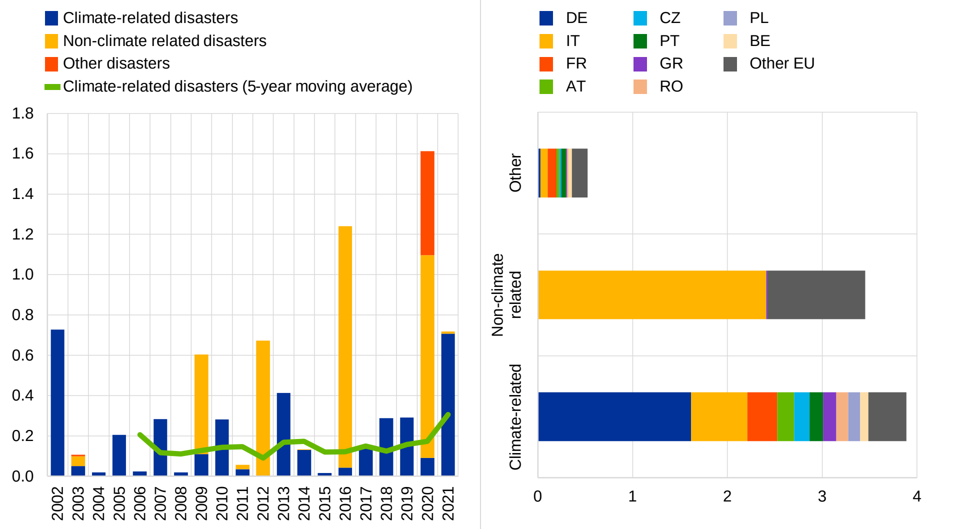
climate-related catastrophes rises with global warming. In addition, as the EUSF is designed purely as a solidarity tool, it does not provide any incentives to take preventive measures – such as requesting adaptation or disaster risk management measures from national governments (see Hochrainer-Stigler et al., 2017).

Despite the EUSF's limitations, it has enjoyed broad uptake among EU Member States. Overall, of the 121 accepted applications submitted by EU countries since 2002, 73% have been climate-related (with floods accounting for more than 50% of all applications), 15% have been related to public health emergencies and 12% have been related to earthquakes or volcanic eruptions. Notably, the amount of funds allocated to climate-related catastrophes has been increasing recently (**Chart 6, left panel**). Such funds have also benefitted 25 different Member States, with Germany being the top recipient (**Chart 6, right panel**), underlining the relevance of disaster relief for major climate-related catastrophes events across most EU Member States.

Chart 6

Accepted applications to the EUSF for climate disaster relief have increased recently and are spread across the EU

EUSF financial support paid, by disaster type	EUSF financial support paid, by EU beneficiary country
(2002-2021; EUR billions)	(2002-2021; EUR billions)



Sources: EUSF data and ECB calculations.
Notes: Both panels cover only the 121 accepted applications submitted by EU countries (all countries except Denmark and Finland) between 2002 and 2021 to the EUSF. "Climate-related disasters" include floods, storms, wildfires and droughts; "non-climate-related disasters" include earthquakes and volcanic disasters; "other disasters" include health emergencies and one man-made disaster (the November 2022 Prestige oil spill off the Spanish coast).

A strengthened European fiscal component for climate-related catastrophe insurance would be beneficial for several reasons. First, while observing the EU principle of subsidiarity, it would be more cost-efficient to pool risks and provide some of the financing at the European level rather than entirely at the national level, given that infrequent large climate-related disasters display weak correlation across EU Member States and across time, and future economic damages from such disasters are highly uncertain. Second, it could provide funding where acute relief and reconstruction costs (including adaptation costs) would otherwise very severely stretch national private and public financing capacity. Third, it could add value when compared with current EU disaster relief instruments via, for example, greater financing power, insuring new risks or providing support on different terms. In particular, if sufficiently attractive and large enough to provide credible incentives, the European fiscal component could have a transformative power above and beyond its financial firepower by making access to funding conditional on specific requirements, such as strengthening private and public sector catastrophe insurance at the national level or meeting certain risk management, mitigation or adaptation standards. This would ultimately help enhance the insurability of damages from climate-related disasters and, moreover, minimise associated economic costs and possible negative spillovers among EU Member States.

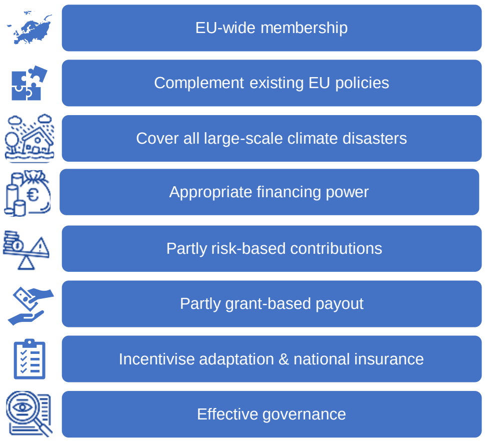
At the same time, differences in the risk profiles of Member States, owing to geographical factors and divergent risk management practices, make the creation of a European fiscal component challenging, from both an operational and a political perspective. While pooling risks would enhance risk diversification as discussed above, it may imply some permanent transfers between regions or countries, and this should be considered in the design and financing structure of any EU fund.

Key principles for a public European backstop solution for climate-related natural disaster risks for EU Member States

A European public component for climate change-related disaster insurance would ideally embed several desirable features and principles to help ensure that it reduces the insurance protection gap effectively and efficiently, while also minimising both the overall costs from future climate-related disasters and the share of these costs borne by the public sector (**Figure 3**). These principles should reflect the nature of climate-related catastrophe risks. They should also draw lessons from the design of other EU-level instruments beyond the EUSF, such as the European Stability Mechanism (ESM), the Single Resolution Fund (SRF) and the EU recovery fund (i.e. Next Generation EU and the Recovery and Resilience Facility) (**Table 2**). These instruments have very different objectives and functions, but they tend, for example, to provide a degree of risk-sharing or solidarity by providing funding for agreed purposes and to make access to financing conditional on specific measures to be taken by recipients.

Figure 3

Key principles for a European public insurance scheme for climate-related natural disaster risk



Source: Authors.

First, as in the case of the EUSF, a fiscal component at European level should be EU-wide.[29] An EU-wide scheme would benefit from the strongest risk pooling and risk diversification, have more funds at its disposal and ultimately have a greater beneficial impact on EU economic resilience than a scheme with more limited participation. Such an approach would also be consistent with key climate objectives and policies being defined at EU level, such as emissions reduction targets and the EU Emissions Trading System.

Second, the scheme should complement and add value beyond existing EU policies and instruments for disaster relief, such as the EUSF. It is therefore important to consider the extent to which existing instruments may be remodelled in line with the outlined principles in order to contribute effectively to reducing the insurance protection gap. One possibility could be to focus a new scheme on providing financial support to Member States for reconstruction, accounting for adaptation needs, on which the EUSF contributes relatively little, and focus the latter on immediate emergency relief. It is also important that any funding which supports reducing the insurance protection gap is not provided at the expense of funding for other climate-related initiatives, in particular initiatives related to mitigation.

Third, an EU-wide scheme should cover all relevant types of climate-related hazards facing EU Member States, such as storms, floods and wildfires, but with a clear focus on infrequent large-scale disasters. This will be key for risk diversification and pooling benefits. Given the different distribution of specific disaster types and associated risks across Member States and EU regions, a wide scope of climate-risk coverage would also help to ensure the scheme's relevance across Member States.

Fourth, sufficient funding should be available to provide meaningful and swift support for large-scale climate disasters. A small fund with a limited pay-out capacity would not be credible for tackling major events. A prefunded solution based on regular,

29 In addition to EU Member States, countries negotiating to join the EU can also apply for EUSF funding.

cumulative contributions from all Member States would be an effective option to achieve a fund of meaningful size. As there are opportunity costs to putting aside funds which may only be drawn on to a limited extent in the short term, total contributions would have to be calibrated to estimated needs. In this regard, it would be efficient to provide any EU scheme with a borrowing capacity to raise funds against either its stock of cumulative contributions or Member State guarantees in the event of large pay-outs, especially given uncertainties around the costs of future economic losses from climate-related disasters.[30] To enable swift pay-outs following large disasters, such borrowing by the scheme could be allowed on a discretionary basis up to a certain ceiling, beyond which further borrowing would have to be agreed at a political level. Under all setups, any accumulated contributions could be invested in investment-grade, liquid green assets, such as bonds compliant with the proposed EU green bond standard, thereby also allowing the fund to support complementary efforts to mitigate climate change and reduce global warming.

Fifth, contributions or guarantees to the scheme should have a risk-based component. The premium structure for Member State contributions should be designed both to incentivise Member States to take appropriate risk reduction measures, including mitigation and adaptation, and to account for their different geographical climate catastrophe risks. A risk-based component in Member State contributions would also help to address issues related to moral hazard (see **Box 2**). At the same time, contributions should maintain some solidarity element given the shared nature of the climate change challenge and individual Member States' limited control over the occurrence of specific catastrophes.

Sixth, as with the EUSF, pay-outs should, at least in part, be in the form of grants to achieve some mutualisation of climate change catastrophe risks. While loan-based support would help fiscally weaker Member States, who could benefit from more favourable borrowing conditions and immediate access to funds, catastrophe risks would still remain a national responsibility. Loan support would also increase public debt levels of the Member States concerned, adversely affecting their debt sustainability. In contrast, the cost of support in the form of grants would be shared by all Member States and would not directly affect national public debt levels.

Seventh, sufficient safeguards should be in place to minimise costs to the scheme. In particular, it must provide credible incentives for Member States to implement adaptation and mitigation measures and reduce the insurance protection gap at a national level. As with the EUSF, the scheme should only be triggered by large, infrequent disasters above a predefined threshold. Pay-outs from the scheme should be conditional on insurable damages being covered by private and public-private schemes at the national level, and could cover only a predefined share of the uninsurable, total public costs to ensure that governments keep sufficient "skin in the game" to pursue ambitious adaptation strategies. Full access should also be conditional on Member States having implemented agreed adaptation strategies and meeting their emissions reduction targets.

[30] See, for instance, Lenaerts et al. (2022).

Eighth, the scheme should have an effective governance structure to guarantee swift pay-outs while ensuring fair and transparent use of funds. Considerations around the degree of discretion and speed in the management and pay-out of funds would have to be balanced against requirements for checks, democratic accountability and transparency. A balance could be found whereby daily management and pay-outs up to a certain ceiling could be decided by the European Commission based on predetermined and politically agreed criteria. Funds would be disbursed to national governments, which would have to provide regular reports on how they are being used. Pay-outs would occur in stages, with a sizeable share disbursed within a set timeframe after the initial request from the Member State concerned, and could be suspended in the case of inadequate use or insufficient reporting.

Box 2
Addressing moral hazard

Moral hazard arising from private insurance

Avoiding moral hazard is a core issue in the design of insurance. Moral hazard represents the risk that the insured party will engage in riskier behaviour in expectation of compensation from the insurer, resulting in higher overall claims for the insurer. The greater the information asymmetry between the insurer and the insured, the higher the risk of moral hazard. Insurers mitigate the financial impact of moral hazard through, among other things, deductibles (i.e. a portion of the loss to be paid by the insured party before the coverage kicks in) and limits to coverage, as well as by offering discounts on premiums when the insured party does not make any claims or takes action to reduce the risk of loss. In traditional reinsurance, the reinsurer can use its technical expertise to assess the risks being ceded by the insurer and hence reduce the impact of moral hazard. In a cat bond transaction, capital market investors face greater moral hazard risk from the party that cedes the risk. This is mitigated by obtaining an independent assessment of the risks being covered by the bond.

Certain measures aimed at reducing the insurance protection gap may risk an increase in moral hazard, as there can be a trade-off between post-disaster insurance payments and ex ante adaptation. For example, mandatory insurance can disincentivise high-risk households and firms from investing in risk mitigation and adaptation by compensating them after disasters.[31] For this reason, impact underwriting and risk-based incentives linked to premiums can be useful to reduce this moral hazard and the related negative impact on welfare.

Moral hazard and the role of the public sector

Moral hazard is not only present between the parties involved in private insurance; it can also be an issue between private insurance parties and the public sector, or between different levels of the public sector. For example, private insurance parties may rely on an explicit or implicit government backstop – such as post-disaster aid – and reduce their own insurance coverage or adaptation

[31] Cohen and Werker (2008) find that expectations of international aid following a disaster reduce countries' investments in disaster preparedness. Similarly, Lewis and Nickerson (1989) show theoretically that federal aid for disaster relief reduces individuals' expenditure on protecting their property from harm. Federal aid can also create adaptation-related moral hazard in other contexts. For example, Annan and Schlenker (2015) demonstrate that federally subsidised yield guarantees reduce farmers' incentives to adapt to extreme heat.

efforts, or lower levels of government may neglect their role in the enforcement of regulations, as the potential losses are covered by higher levels of government.

As with private insurance, moral hazard should therefore be taken into account in the design of schemes that involve the public sector in some form. One way to do this is by matching, insofar as possible, the responsibility for providing disaster relief with the responsibility for enforcing the relevant regulations (e.g. planning regulations). Other policy options are to incentivise risk mitigation and adaptation either in the design of the insurance itself or through other policies. Recent evidence from the United States shows that, while the moral hazard effects from disaster aid reduce adaptation, federal subsidies for investment in adaptation are more than sufficient to correct for this moral hazard (Fried, 2021).[32] A crucial consideration concerning the insurance protection gap is that the public sector is currently in any case the holder of the residual risk, which makes it liable for large climate-related catastrophe losses that are likely to increase in frequency and magnitude. Policies aimed at enhancing both adaptation and mitigation of climate-related events are therefore needed to increase the resilience of the economy to climate change and reduce the insurance protection gap.

Moral hazard arising from a possible EU-wide scheme

With a common backstop for climate disaster costs, the moral hazard risk from a possible EU-wide scheme is that Member States will not make sufficient effort to reduce climate risks and the insurance protection gap at the national level, thereby exposing any EU-wide scheme and the EU economy as a whole to higher residual risks when disaster strikes. For example, in the presence of an ill-designed common backstop which supports recovery after disaster strikes, Member States may become less inclined to:

- implement measures to increase private sector insurance and reinsurance of climate-related risks;
- set up adequate public-private partnerships or risk transfer arrangements;
- build up appropriate fiscal buffers;
- implement adaptation strategies (e.g. regarding building standards and rules on building in flood-prone areas or other areas exposed to climate catastrophe risks);
- meet emissions reduction targets.

To address these moral hazard concerns, certain mechanisms, controls and safeguards could be introduced into any EU-wide scheme. For example, access to an EU-wide scheme could be conditional on Member States having implemented agreed adaptation strategies and obligations to curb climate change and the risks associated with it. Implementing commonly agreed regulations and standards (including some minimum standards on building regulations), and consistent adaptation strategies, could also be a prerequisite to creating an EU-wide scheme, the aim being that Member States should have similar (minimum) public and private arrangements in place to reduce the insurance protection gap in their jurisdictions. As with private insurance, there could also be a deductible to be paid by other layers of protection before an EU-wide scheme covers any

[32] The resulting adaptation is estimated to reduce the damage from climate change by approximately 30% and the associated welfare costs by approximately 5% (Fried, 2021).

losses. This would mean that common funds would only be available for the tail risk associated with major events, thereby helping to curb moral hazard.

3 Complementarity with wider EU policy initiatives

The policy options set out in this discussion paper to address the climate insurance protection gap also intersect with and complement some wider policy initiatives. These include the EU strategy on adaptation to climate change, and initiatives relating to the EU's CMU and the incorporation of climate risks into banking supervision.[33]

As part of the new EU strategy on adaptation to climate change adopted by the European Commission in February 2021, the Climate Resilience Dialogue provides a forum for private sector (re)insurers, policymakers and other stakeholders to exchange views on how to address the losses from climate-related disasters and to identify how the insurance industry can contribute more to climate adaptation.[34] This discussion paper can inform this debate.

By enhancing the resilience of the EU insurance sector, measures aimed at reducing the climate insurance protection gap can help strengthen EU capital markets, notably the green segment. A robust insurance sector is not only important to protect against the rising catastrophe risks associated with climate change; it is also a prerequisite for greater institutional investment in green capital markets. The ladder approach proposed in this discussion paper would help to ensure that the insurance sector can better manage the risks emanating from climate-related natural disasters. It is thus complementary to ongoing efforts, as notably outlined in the 2021 EU Sustainable Finance Strategy[35] and the 2020 CMU action plan,[36] to address the protection gap, integrate climate and sustainability risks into insurers' risk management, and enhance insurance companies' contribution to the green transition, including via capital market instruments such as European long-term investment funds (ELTIFs). The Solvency II review proposals of the European Commission outline, among other things, measures that contribute to these goals.[37] They would also require EIOPA to review regularly the scope and the calibration of parameters of the standard formula pertaining to natural catastrophe risk.[38]

Further progress on the EU's CMU and sustainable finance agendas is also important in helping to mobilise the private funding needed to reduce the climate insurance protection gap. Initiatives to promote the depth, liquidity and cross-border integration of EU capital markets can contribute to growing the universe of investors in green projects and financial products, including cat bonds. To this end, EU policymakers need to make swift progress on implementing the outstanding policy

33 See ECB (2022a).

34 See "EU Adaptation Strategy" on the European Commission's website.

35 See European Commission (2021a).

36 See European Commission (2020b).

37 See European Commission (2021b).

38 See EIOPA (2021b).

proposals under the 2020 CMU action plan. These are aimed in particular at increasing the information available to investors about companies and financial products, the tax treatment of equity, and the harmonisation of insolvency laws and withholding taxes. In addition, further progress on improving sustainability disclosures and the ongoing work on agreeing a common standard for EU green bonds can help to direct more funding towards green projects.[39]

Finally, regarding the banking sector, as discussed in **Section 1.2**, a lack of insurance may increase risks associated with lending secured by property exposed to climate-related catastrophes or prevent some property qualifying as collateral. This may trigger higher capital needs for existing lending and could lower credit supply. However, physical risk can also be mitigated by improving adaptation of properties. Given these considerations, targeted prudential/macroprudential regulations in the banking sector may be needed to enhance its resilience to the implications of a persistent climate insurance protection gap.[40]

[39] See Born et al. (2021).

[40] See, for example, the proposed amendments to Article 208, paragraphs 3b and 5, in the review of the Capital Requirements Regulation, aimed at (i) reinforcing the requirement for banks to monitor the insurance of immovable properties taken as credit protection against the risk of damage, including from physical risk, and (ii) clarifying the relevance of improvements to the "resilience, protection and adaptation to physical risks of the building or housing unit". In addition, in the context of the Thematic Review on Climate and Environmental Risks (ECB, 2022b), the ECB identified as good practice for banks to consider the availability of insurance schemes and government protection schemes in bank lending policies.

4 Conclusion

Catastrophe insurance plays a key role in mitigating the losses arising from extreme weather and climate events. Only a quarter of such losses are currently covered in Europe, resulting in burdens on individual households and businesses, and macroeconomic and fiscal costs at the local, regional and national levels. Addressing this insurance protection gap would provide substantial economic benefits. Climate change – which is likely to drive more frequent and more devastating catastrophes – adds greater urgency to the need to reduce the protection gap, particularly given that it may cause the gap to widen further.

This discussion paper suggests possible actions which should be considered to reduce the climate insurance protection gap, incentivise risk mitigation and adaptation measures, and lower the share of economic losses from major disasters borne by the public sector. In particular, it proposes a ladder approach that builds on the existing frameworks of private (re)insurance, cat bonds and national public sector interventions. It also discusses the possible case for more concerted and forward-looking policy coordination and intervention at the national and EU level in relation to particularly severe disasters.

The paper aims to foster discussion and solicit feedback on the principles, framework and possible policy actions. The ECB and EIOPA will continue to analyse the implications of the insurance protection gap and the policy options set out in this paper and would welcome comments and feedback on all aspects of its content. Comments should be sent to this email, ideally by 15 June 2023: ecb_eiopa_staff_protection_gap@eiopa.europa.eu

5 Appendix

Table 2

Existing wider EU policy initiatives

	EU Solidarity Fund	Next Generation EU/Recovery and Resilience Facility	Single Resolution Fund	European Stability Mechanism
Description	An EU instrument which provides financial support (grants) to Member States in the event of a major natural disaster that, in principle, is non-insurable. Support for both structural and temporary repairs as well as acute relief to the population.	A temporary EU instrument (expires 2026) to provide both grant and loan-based financial support to Member States for financing of (post-)pandemic recovery on the basis of national recovery plans, approved at EU level and subject to meeting pre-defined milestones.	A common fund for bearing the resolution costs, after application of a bail-in, arising when large or cross-border banks in the banking union fail and are put into resolution.	The ESM provides financial assistance to euro area countries experiencing or threatened by severe financing problems. This assistance is granted only if it is proven necessary to safeguard the financial stability of the euro area as a whole and of ESM members.
Size	Up to €500 million (2011 prices) per year, plus the unspent allocation from the previous year.	Up to €723.8 billion over the entire period 2021-2026, of which €385.8 billion is available in loans and €338 billion in grants.	Approximately €55 billion (target level is 1% of all covered deposits).	The ESM has a lending capacity of €500 billion.
Funding	Financed by exceptional borrowing by the Commission on behalf of the EU based on higher national commitments to the EU budget.	Financed by exceptional borrowing by the Commission on behalf of the EU based on higher national commitments to the EU budget. Allocation of funds between Member States based on pre-agreed criteria with a "solidarity" aspect (Member State GDP, population and unemployment).	Risk-based ex ante fees paid by banks.	The ESM has €80 billion of paid-in capital and an additional €620 billion in "callable" capital to be contributed when requested. These sums put the ESM in a strong position to borrow on the bond markets.
Backstop	No	No	ESM: In the event that the SRF is depleted, the ESM can act as a backstop and provide a revolving credit line with a nominal cap set at €68 billion.	No
Safeguards	Only accessible for major disasters, defined as above €3 billion in 2011 prices, or above 0.6% of GNI of the EU Member State/accession country concerned, or 1.5% of regional GNI), or public health emergency (above €1.5 billion in 2011 prices, or more than 0.3% of Member State GNI). Only partial coverage of damages, and pay-outs limited to €500 million/year.	Member States have to complete structural reforms as part of national recovery plans, whereby the greater the funding received, the greater the emphasis there is on reforms.	The contributions are allocated to different "national compartments" during the transitional period. These are progressively being merged and will cease to exist after 2023. Bail-in of at least 8% before the SRF can contribute towards absorbing losses or recapitalising a bank (which is capped at a 5% contribution). Banks are subject to minimum requirements for own funds and eligible liabilities (MREL).	The ESM can use several instruments: loans within a macroeconomic adjustment programme, primary and secondary market purchases, precautionary credit lines, loans for indirect bank recapitalisation, and direct recapitalisation of institutions. All instruments have safeguards, i.e. eligibility and conditionality criteria. Some criteria are set very high, e.g. for direct recapitalisation of institutions, and have therefore never been used.

	EU Solidarity Fund	Next Generation EU/Recovery and Resilience Facility	Single Resolution Fund	European Stability Mechanism
Governance	The European Commission assesses applications and prepares implementing decisions to be approved by the Council.	Subject to Member States meeting the agreed milestones and targets in their national recovery plans, the European Commission prepares implementing decisions to be approved by the Council.	The Single Resolution Board (SRB) decides on the use in a resolution scheme. Once the SRB has adopted a resolution scheme, it sends it to the European Commission. The scheme may enter into force only if no objection is raised by the Commission or the Council within a period of 24 hours.	The ESM governing bodies are the Board of Governors and the Board of Directors. The Board of Governors is the highest decision-making body of the ESM. It comprises government representatives of each of the 19 ESM shareholders with responsibility for finance.
Legal basis	Article 175(3) and Article 212(2) of the Treaty on the Functioning of the European Union, Council Regulation (EC) No 2012/2002 of 11 November 2002 establishing the European Union Solidarity Fund and Regulation (EU) No 661/2014 of the European Parliament and of the Council of 15 May 2014 amending Council Regulation (EC) No 2012/2002 establishing the European Union Solidarity Fund.	Borrowing is governed by the EU Recovery Instrument Regulation. Use of funds is largely governed by the Recovery and Resilience Facility Regulation.	Established under the Single Resolution Mechanism Regulation. An intergovernmental agreement between euro area Member States (and Member States which have entered into close cooperation with the ECB and joined the Single Supervisory Mechanism) governs the transfer of funds to the SRF.	The ESM Treaty.

Source: Authors.

6 References

Aligishiev, Z., Massetti, E. and Bellon, M. (2022), "Macro-Fiscal Implications of Adaptation to Climate Change", *Staff Climate Notes*, No 2, International Monetary Fund (IMF), March.

Alogoskoufis, S., Carbone, S., Coussens, W., Fahr, S., Giuzio, M., Kuik, F., Parisi, L., Salakhova, D. and Spaggiari, M. (2021), "Climate-related risks to financial stability", *Financial Stability Review*, ECB, May.

Ando, S., Roch, F., Wiriadinata, U. and Fu, C. (2022), "Sovereign Climate Debt Instruments: An Overview of the Green and Catastrophe Bond Markets", *Staff Climate Notes*, No 4, IMF, July.

Annan, F. and Schlenker, W. (2015), "Federal Crop Insurance and the Disincentive to Adapt to Extreme Heat", *American Economic Review*, Vol. 105(5), May, pp. 262-266.

Bakkensen, L. and Barrage, L. (2022), "Going Underwater? Flood Risk Belief Heterogeneity and Coastal Home Price Dynamics", *The Review of Financial Studies*, Vol. 35(8), August, pp. 3666-3709.

Bank of England (BoE) (2019), "The 2021 biennial exploratory scenario on the financial risks from climate change", *Discussion Paper*, December.

BCBS (2021), "Climate-related risk drivers and their transmission channels", April.

Ben-Shahar, O. and Logue, K.D. (2016), "The Perverse Effects of Subsidized Weather Insurance", *Stanford Law Review*, Vol. 68(3), March, pp. 571-626

Blickle, K.S. and Santos, J.A.C. (2022), "Unintended Consequences of 'Mandatory' Flood Insurance", *Staff Reports*, No 1012, Federal Reserve Bank of New York, April.

BMA (2021), "Three-day Registration for Special Purpose Insurers Issuing Bonds", 20 August.

Born, A., Giuzio, M., Lambert, C., Salakhova, D., Schölermann, H. and Tamburrini, F. (2021), "Towards a green capital markets union: developing sustainable, integrated and resilient European capital markets", *Macroprudential Bulletin*, Issue 15, ECB, October.

Botzen, W., Deschenes, O. and Sanders, M. (2019), "The Economic Impacts of Natural Disasters: A Review of Models and Empirical Studies", *Review of Environmental Economics and Policy*, Vol. 13(2), pp. 167-188.

Carney, M. (2015), "Breaking the Tragedy of the Horizon—Climate Change and Financial Stability." Speech delivered at Lloyd's of London, September 29.

Carter, M.R., Little, P.D., Mogues, T. and Negatu, W. (2007), "Poverty Traps and Natural Disasters in Ethiopia and Honduras", *World Development*, Vol. 35(5), May, pp. 835-856.

Cohen, C. and Werker, E.D. (2008), "The Political Economy of 'Natural' Disasters", *Journal of Conflict Resolution*, Vol. 52(6), December, pp. 795-819.

Cortés, K.R. and Strahan, P.E. (2017), "Tracing out capital flows: How financially integrated banks respond to natural disasters", *Journal of Financial Economics*, Vol. 125(1), July.

Cummins, J.D. and Trainar, P. (2009), "Securitization, Insurance, and Reinsurance", *The Journal of Risk and Insurance*, Vol. 76(3), September, pp. 463-492.

Demers-Belanger, K. and Lai, V.S. (2020), "Diversification benefits of cat bonds: An in-depth examination", *Financial markets, institutions and instruments*, Vol. 29(5), December, pp. 165-228.

ECB (2022a), "Walking the talk – Banks gearing up to manage risks from climate change and environmental degradation – Results of the 2022 thematic review on climate-related and environmental risks", November.

ECB (2022b), "Good practices for climate-related and environmental risk management – Observations from the 2022 thematic review", November.

ECB/ESRB (2021), "Climate-related risk and financial stability", ECB/ESRB Project Team on climate risk monitoring, July.

ECB/ESRB (2022), "The macroprudential challenge of climate change", ECB/ESRB Project Team on climate risk monitoring, July.

EIOPA (2020), "Issues paper on shared resilience solution for pandemics", July.

EIOPA (2021a), "Report on non-life underwriting and pricing in light of climate change", EIOPA-BoS-21/259, July.

EIOPA (2021b), "Methodological paper on potential inclusion of climate change in the Nat Cat standard formula", July.

EIOPA (2022), "Discussion paper on physical climate change risks", July.

EIOPA (2023), "Impact underwriting: Report on the Implementation of Climate-Related Adaptation Measures in Non-Life Underwriting Practices", EIOPA-BoS-22-593, February.

European Commission (2020a), "Debt Sustainability Monitor 2019", *Institutional Paper*, No 120, January, Box 5.3 "Including climate change risks in the DSA: concepts and definition".

European Commission (2020b), "Capital markets union 2020 action plan: A capital markets union for people and businesses", September.

European Commission (2021a), "Strategy for financing the transition to a sustainable economy", July.

European Commission (2021b), "Proposal for a Directive of the European Parliament and of the Council amending Directive 2009/138/EC as regards proportionality, quality of supervision, reporting, long-term guarantee measures, macro-prudential tools, sustainability risks, group and cross-border supervision", September.

European Commission (2022), "Fiscal Sustainability Report 2021", *European Economy – Institutional Paper*, No 171, April.

European Commission (2023), "SEAR – advance payments under European Union Solidarity Fund (EUSF)", *Programme Statements*, No DB2023.

European Environment Agency (2022), "Economic losses from climate-related extremes in Europe", *Indicators*, February.

European Systemic Risk Board (ESRB) (2020), "Positively green: Measuring climate change risks to financial stability", June.

Fache Rousová, L., Giuzio, M., Kapadia, S., Kumar H., Mazzotta, L., Parker, M. and Zafeiris, D. (2021), "Climate change, catastrophes and the macroeconomic benefits of insurance", *Financial Stability Report*, EIOPA, July.

Faiella, I. and Natoli, F. (2018), "Natural catastrophes and bank lending: the case of flood risk in Italy", *Occasional Papers*, No 457, Banca d'Italia, October.

Federal Ministry of Finance (2021), "Federal government and Länder support flood-hit regions", *press release*, Germany, 18 August.

Felbermayr, G. and J. Groeschl (2014), "Naturally negative: the growth effects of natural disasters", *Journal of Development Economics*, Vol. 111, pp. 92-106.

Feyen, L., Ciscar, J.C., Gosling, S., Ibarreta, D. and Soria, A. (eds.) (2020), "Climate change impacts and adaptation in Europe", *JRC Science for Policy Report*, JRC PESETA IV final report, Joint Research Centre.

Financial Protection Forum (2021), "Development of Catastrophe Bonds for Sovereign Disaster Risk Transfer", *Knowledge Exchange Series on Building Sovereign Financial Resilience in Middle Income Countries*, November.

Financial Stability Board (FSB) (2020), "The implications of climate change for financial stability", November.

Fried, S. (2021), "Seawalls and stilts: A quantitative macro study of climate adaptation", *Working Paper*, No 2021/07, Federal Reserve Bank of San Francisco, January.

Gagliardi, N., Arévalo, P. and Pamies, S. (2022), "The Fiscal Impact of Extreme Weather and Climate Events: Evidence for EU Countries", *Discussion Paper*, No 168, European Commission, July.

Gallagher, J. (2014), "Learning about an Infrequent Event: Evidence from Flood Insurance Take-Up in the United States", *American Economic Journal: Applied Economics*, Vol. 6(3), July, pp. 206-233.

Gamper, C., Signer, B., Alton, L. and Petrie, M. (2017a), "Managing disaster-related contingent liabilities in public finance frameworks", OECD Working Papers on Public Governance, No 27, OECD, June.

Garmaise, M.J. and Moskowitz, T.J. (2009), "Catastrophic Risk and Credit Markets", *The Journal of Finance*, Vol. 64(2), April, pp. 657-707.

Hochrainer-Stigler, S., Linnerooth-Bayer, J. and Lorant, A. (2017), "The European Union Solidarity Fund: an assessment of its recent reforms", *Mitigation and Adaptation Strategies for Global Change*, Vol. 22, pp. 547-563.

International Association of Insurance Supervisors (IAIS) and Sustainable Insurance Forum (SIF) (2018), "Issues Paper on Climate Change Risks to the Insurance Sector", July.

IAIS and SIF (2021), "Application Paper on the Supervision of Climate-related Risks in the Insurance Sector", May.

Insurance Authority of Hong Kong (2021), "Pilot Insurance-linked Securities Grant Scheme", 3 May.

InsuranceERM (2023), "Axa plans 35% cut to Axa XL Re's nat cat exposure in 2023", 23 February.

Islam, S.N. and Winkel, J. (2017), "Climate Change and Social Inequality", *DESA Working Papers*, No 152, United Nations Department of Economic and Social Affairs, October.

Kahn, M.E., Mohaddes, K., Ng, R.N.C., Pesaran, M.H., Raissi, M. and Yang, J.-C. (2021), "Long-term macroeconomic effects of climate change: A cross-country analysis", *Energy Economics*, Vol. 104, pp. 573-578.

Klomp, J. (2014), "Financial fragility and natural disasters: An empirical analysis", *Journal of Financial Stability*, Vol. 13, August, pp. 180-192.

Klomp, J. and Valckx, K. (2014), "Natural disasters and economic growth: a meta-analysis", *Global Environmental Change*, Vol. 26, May, pp. 183-195.

Kousky, C. (2014), "Informing Climate Adaptation: A Review of the Economic Costs of Natural Disasters", *Energy Economics*, Vol. 46, November, pp. 576-592.

Lenaerts, K., Tagliapietra, S. and Wolff, G. (2022), "How can the European Union adapt to climate change while avoiding a new fault line?", *Policy Contribution*, No 11/22, Bruegel, June.

Lewis, T. and Nickerson, D. (1989), “Self-insurance against natural disasters”, *Journal of Environmental Economics and Management*, Vol. 16(3), May, pp. 209-223.

Linnerooth-Bayer, J., Surminski, S., Bouwer, L.M., Noy, I. and Mechler, R. (2019), “Insurance as a Response to Loss and Damage?”, in Mechler, R., Bouwer, L.M., Schinko, T., Surminski, S. and Linnerooth-Bayer, J. (eds.), *Loss and Damage from Climate Change*, Springer Book, pp. 483-512.

Maynard, T. and Ranger, N. (2012). “What Role for “Long-term Insurance” in Adaptation? An Analysis of the Prospects for and Pricing of Multi-year Insurance Contracts”, *The Geneva Papers on Risk and Insurance - Issues and Practice*, Vol. 37, pp. 318-339.

MAS (2021), “Insurance Linked Securities Grant Scheme”, 27 January.

Melecky, M. and Raddatz, C. (2011), “How Do Governments Respond after Catastrophes? Natural-Disaster Shocks and the Fiscal Stance”, *Policy Research Working Papers*, No 5564, World Bank.

Network for Greening the Financial System (NGFS) (2019), “A call for action: Climate change as a source of financial risk”, April.

Noy, I. (2009), “The macroeconomic consequences of disasters”, *Journal of Development Economics*, Vol. 88(2), March, pp. 221-231.

OECD (2017), “OECD Recommendation on Disaster Risk Financing Strategies”, February.

OECD (2021), “Enhancing Financial Protection Against Catastrophe Risks: The Role of Catastrophe Risk Insurance Programmes”, October.

Owen, S. and Noy, I. (2019), “Regressivity in Public Natural Hazard Insurance: a Quantitative Analysis of the New Zealand Case”, *Economics of Disasters and Climate Change*, Vol. 3(3), June, pp. 235-255.

Parker, M. (2018), “The impact of disasters on inflation”, *Economics of Disasters and Climate Change*, Vol. 2(1), April, pp. 21-48.

Poontirakul, P., Brown, C., Seville, E., Vargo, J. and Noy, I. (2017), “Insurance as a Double-Edged Sword: Quantitative Evidence from the 2011 Christchurch Earthquake”, *The Geneva Papers on Risk and Insurance – Issues and Practice*, Vol. 42(4), October, pp. 609-632.

Prognos (2022), “Estimation of costs resulting from climate change in Germany”, prepared for the Federal Ministry for Economic Affairs and Climate Action (BMWK) and the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), July.

Tesselaar, M., Botzen, W.J.W., Haer, T., Hudson, P., Tiggeloven, T. and Aerts, J.C.J.H. (2020), "Regional Inequalities in Flood Insurance Affordability and Uptake under Climate Change", *Sustainability*, Vol. 12(20), October, p. 8734.

Trottier, D.-A. and Lai, V.S. (2017), "Reinsurance or CAT Bond? How to Optimally Combine Both", *The Journal of Fixed Income*, Vol. 27(2), Fall 2017, pp. 65-87.

von Peter, G., von Dahlen, S. and Saxena, S.C. (2012), "Unmitigated disasters? New evidence on the macroeconomic cost of natural catastrophes", *BIS Working Papers*, No 394, Bank for International Settlements, December.

Worthington, A. and Valadkhani, A. (2007), "Measuring the impact of natural disasters on capital markets: an empirical application using intervention analysis", *Applied Economics*, Vol. 36, Issue 19, February, pp. 2177-2186.

Zenios, S.A. (2022), "The risks from climate change to sovereign debt", *Climatic Change*, No 172(30), June, pp. 1-19.

Acknowledgements
This discussion paper benefited from contributions by the following listed authors.

Nicholai Benalal
European Central Bank, Frankfurt am Main, Germany; email: Nicholai_Alexander.Benalal@ecb.europa.eu

Marien Ferdinandusse
European Central Bank, Frankfurt am Main, Germany; email: Marien.Ferdinandusse@ecb.europa.eu

Margherita Giuzio
European Central Bank, Frankfurt am Main, Germany; email: Margherita.Giuzio@ecb.europa.eu

Sujit Kapadia
European Central Bank, Frankfurt am Main, Germany; email: Sujit.Kapadia@ecb.europa.eu

Miles Parker
European Central Bank, Frankfurt am Main, Germany; email: Miles.Parker@ecb.europa.eu

Linda Rousová
European Central Bank, Frankfurt am Main, Germany; email: Linda.Fache_Rousova@ecb.europa.eu

Hanni Schölermann
European Central Bank, Frankfurt am Main, Germany; email: Hanni.Schoelermann@ecb.europa.eu

Elisa Telesca
European Central Bank, Frankfurt am Main, Germany; email: Elisa.Telesca@ecb.europa.eu

Pär Torstensson
European Central Bank, Frankfurt am Main, Germany; email: Paer_Niclas.Torstensson@ecb.europa.eu

Casper Christophersen
European Insurance and Occupational Pensions Authority, Frankfurt am Main, Germany; email: Casper.Christophersen@eiopa.europa.eu

Hradayesh Kumar
European Insurance and Occupational Pensions Authority, Frankfurt am Main, Germany; email: Hradayesh.Kumar@eiopa.europa.eu

Luisa Mazzotta
European Insurance and Occupational Pensions Authority, Frankfurt am Main, Germany; email: Luisa.Mazzotta@eiopa.europa.eu

Marie Scholer
European Insurance and Occupational Pensions Authority, Frankfurt am Main, Germany; email: Marie.Scholer@eiopa.europa.eu

Pamela Schuermans
European Insurance and Occupational Pensions Authority, Frankfurt am Main, Germany; email: Pamela.Schuermans@eiopa.europa.eu

Dimitris Zafeiris
European Insurance and Occupational Pensions Authority, Frankfurt am Main, Germany; email: Dimitris.Zafeiris@eiopa.europa.eu

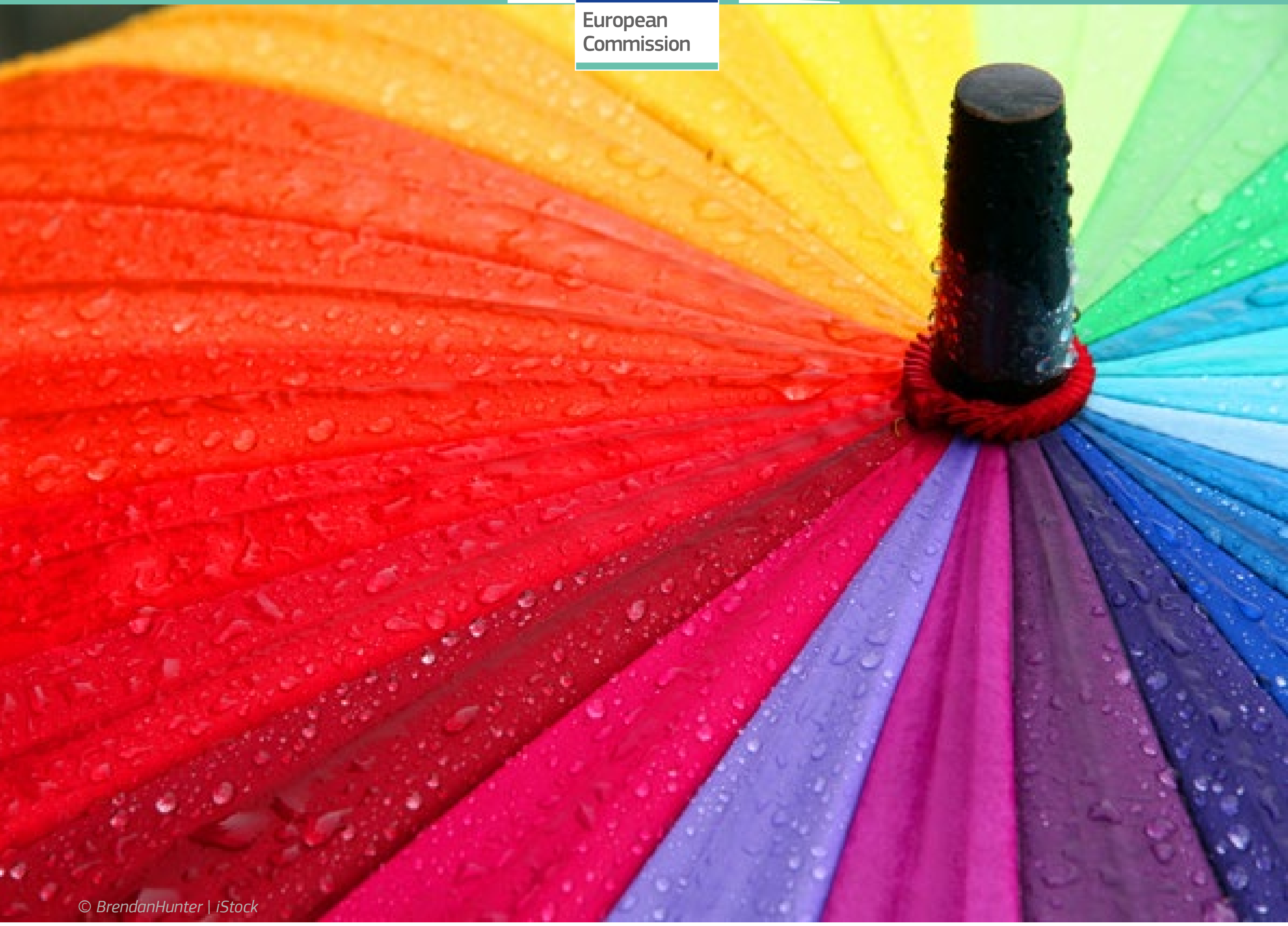
Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

For specific terminology please refer to the ECB glossary (available in English only).

PDF ISBN update identifier, ISSN update identifier, doi:update identifier, update identifier

Annex 530

“Using insurance in adaptation to climate change”, *European Commission*, 2018



Using insurance in adaptation to climate change

Climate Action

Printed by the Publications Office in Luxembourg
Luxembourg: Publications Office of the European Union, 2018

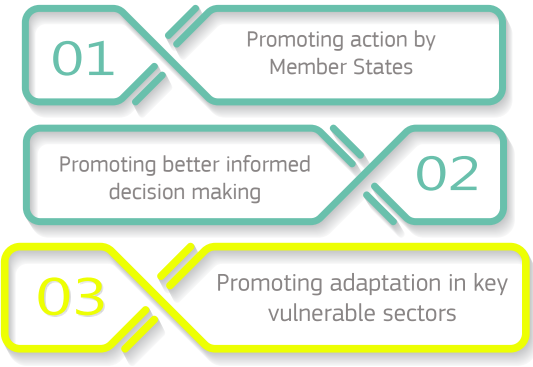
Print	*ISBN 978-92-79-77289-4*	*doi:10.2834/745494*	*ML-06-17-493-EN-C*
PDF	*ISBN 978-92-79-77288-7*	*doi:10.2834/036674*	*ML-06-17-493-EN-N*

HOW CAN INSURANCE INCREASE RESILIENCE TO CLIMATE-RELATED DISASTER RISK?

Climate change is happening. We are reminded of it through an increase in frequency and destructive force of extreme weather events around the globe. Dealing with the consequences requires major financial efforts to compensate for losses. Insurance has attracted much attention as a tool in climate risk management in this context. In addition to financial compensation for losses after an extreme weather event, insurance can provide incentives to reduce risk. This brochure presents the main findings of a study into insurance mechanisms dealing with climate-related extreme weather events[1].

Policy background

The EU Adaptation Strategy[2] outlines objectives and actions that should contribute to a more climate-resilient Europe. The three objectives are:



The third objective encourages the use of insurance against natural and man-made disasters.

The European Commission's Green Paper on the insurance of natural and man-made disasters was published in 2013 as part of the Adaptation Strategy package[3]. It aims to encourage improvement in the ways insurers help to manage climate change risks, to increase the market access of natural disaster insurance and to release the full potential of insurance pricing and other financial products.

The basic principles of insurance against extreme weather events are presented in this brochure. Based on these principles and building on an inventory of insurance mechanisms and contributions from stakeholders, this leaflet presents good practices and a set of recommendations for action.

Insurance as a tool against extreme weather events

Insurance transfers risk from an insured person, object or organisation to an insurer. For extreme weather, this is a valuable tool because the financial damage does not turn into long term economic damage if a house or a business can be rebuilt or compensated for.

Before an extreme weather event can be insured, an insurer should be able to identify the risk and to quantify it. Of course, an insurer should be able to bear the costs if the extreme event actually occurs. One last important element of insurability is, that it cannot be known to anyone how, where and where exactly the extreme event will take place – it needs to be random.

© Alija | iStock

1. *Ramboll and IVM (2017), Insurance of weather and climate-related disaster risk: An inventory and analysis of mechanisms to support damage prevention in the EU*
2. *COM (2013) 216*
3. *COM (2013) 213*

Who is at risk?

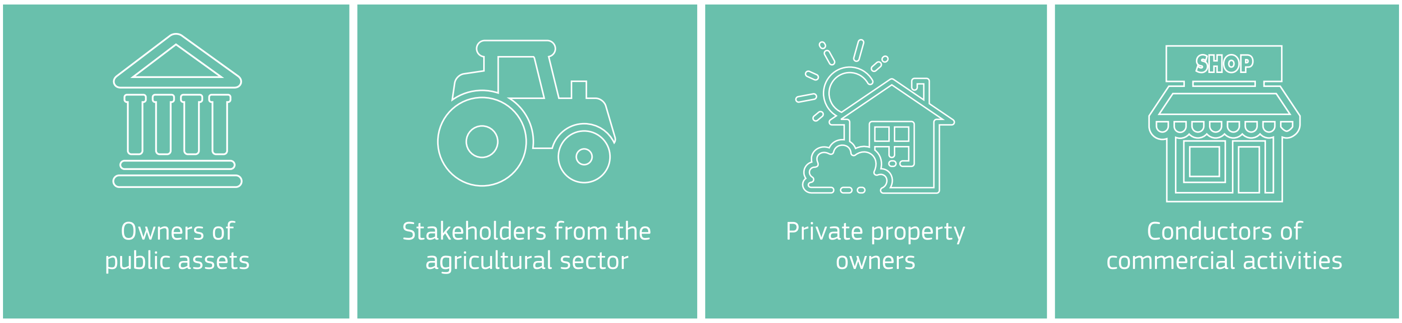
As a consequence of climate change, extreme weather events such as floods, droughts, heat waves and storms are becoming more common, accompanied by an overall increase in risk. This places an increasing burden on the public budgets, insurers and people governments alike in order to absorb these impacts. To tackle such challenges, insurance or insurance-like mechanisms can make society more resilient to the impacts of extreme weather events in several ways:

- Insurance mechanisms can provide **financial compensation** for large disaster losses so that those affected can **recover faster**. The sooner and more comprehensive the recovery, the smaller the impacts of a disaster are likely to be in the long run, which helps to make society more resilient.

- Insurance companies can play a large role in **assessing**, **communicating and signalling risk** through premiums, deductibles and payments, so that those at risk can have a better understanding of the threat(s) posed.

- Stakeholders involved in the insurance sector can generate **incentives or requirements for risk management**, which in turn can **limit the potential impacts** of an extreme weather event. This could happen through price signalling (home-owners who fortify their roofs to be ready for hail storms, could be charged with a lower premium, or a lower deductible). Another option would be to include requirements that relate to resilience in the insurance policy: if an insurance-taker does not take any measures against the risk to which he/she is exposed, the pay-out will be lower.

The types of stakeholder discussed in this analysis can be divided into the following categories:



How can an insurance scheme be assessed?

What makes an insurance scheme perform well? Long term cost and benefits of insurance remain the main indicator. For climate change, these costs and benefits should be seen together with a broad range of risk management tools (prevention, protection, early warning).

The risk management objectives depend on the expectations that governments, insured parties or insurers may have.

An insurance scheme based on **solidarity** will achieve maximum coverage in order to evenly distribute risk.

A **climate risk management insurance** will increase risk awareness and provide incentives to increase resilience through adaptation measures.

The trade-off between premium affordability and risk-reduction incentives
Insurance companies distribute financial risk amongst policyholders, and risk-based premiums can incentivise individual policyholders to reduce risk. However, insurance becomes less attractive for high-risk households or farmers when premiums reflect the underlying risk. Although lower risk policyholders have a weaker incentive to reduce risk, they are more likely to buy insurance since premiums are more affordable.
This trade-off between premium affordability and risk-reduction incentives is important but difficult to balance, and is often influenced by the differing risk management objectives of individual countries and/or stakeholder groups. The differing risk management objectives show that there could be room for more open and transparent engagement of, and collaboration with, the various stakeholders involved in the risk management process.

Advancing solutions: What works?

When considering insurance as a tool in climate risk management, practice in the EU shows that some features of insurance consistently make it perform better.

The consistent characteristics of insurance in well-performing countries across the three archetypes of insurance schemes are displayed here below.

Understanding what makes insurance more performant is useful for guiding action. Sharing of knowledge and practice between member states and applying lessons from one to another would ideally be brought into practice.

Summary of features leading to high or low cost-effectiveness of insurance in the private property sector

 **High-performing**	 **Low-performing**
Multiple extreme weather **risks** (floods, storms, hail, etc.) are combined in a **single** insurance **product**	Extreme weather risks are separately insured
Purchase of **extreme weather** insurance is connected to a far more **common** and enforced product (e.g. mortgage contracts, fire insurance)	Lax enforcements of requirements to buy insurance
Collaboration between **public** and **private** sectors with a **commonly stated and understood objective**. Governments and the insurance sector exchange data, set common objectives and divide responsibilities.	Low overall insurance coverage
Provision of a **national pool** or **public reinsurance** / support for catastrophic losses	Consumers are reliant on direct public compensation for extreme weather event losses
A tradition of **collaboration** between the **public** and **private** sector risk managers	

Successful collaboration between public and private stakeholders:
In ***France***, the insurance industry's contribution to extreme weather risk management is fairly well integrated, addressing risk transfer, disaster risk reduction financing, and data sharing for a better governance. The public and private sectors have a long-standing cooperation, put in place by the non-profit French Association for Disaster Risk Reduction (AFPCN) in 2001. The AFPCN is supported by government departments and brings together the DRR community to promote a coordinated approach. Its activities include stakeholder dialogue, exchange of good practice, and research.

In ***Denmark***, flood insurance provision is provided though the Storm Council, a body that brings stakeholders together and shapes their interaction within the framework of a single common goal (i.e. the provision of storm surge and fluvial flood insurance). In recent years the Storm Council has benefitted from the greater involvement of private sector insurers.

In the ***United Kingdom***, the universal provision of flood insurance is characterized by a series of negotiations between the British Government and the insurance industry, and what the respective roles of the two should be.

Summary of features leading to high or low cost-effectiveness of insurance in the private property sector

High-performing	**Low-performing**
The use of insurance against **multiple risks** (with a focus on yield insurance)	Only specific weather-event insurance products are available
Requirements to insure **all cultivated land**	Only land with a specific crop must be insured
Premium **subsidies** to direct investment in **multi-risk** policies	The presence of ad-hoc government compensation not tied to insurance coverage in the case of truly extreme events
Pool-like structures or **public reinsurance** for specific time-bound risks, such as frost and droughts	
A tradition of **collaboration** between the **public** and **private** sector risk managers	

Examples of insurance against multiple risks in the agricultural sector
Spain and Austria possess similar features that contribute to the overall cost-effectiveness of their insurance schemes against climate-related risks. Both countries are characterised by a large presence of multi-risk insurance products compared to other markets, and relatively high premium subsidies of about 50% of the total premium. The majority of insurance coverage is provided for by a single overarching body that has the overall strategic aim of improving agricultural risk-management strategies. In Austria, this is done by a mutual insurance company (Österreichische Hagelversicherung) and in Spain by the members of a co-insurance pool (Agroseguro).
The benefits of having a single organising body could be the following:

- easier access to reinsurance or capital in the case of large agricultural disasters or general economies of scale, facilitating the development of risk reduction or management strategies.
- a single body provides a platform, which makes it clear where climate risk management takes place.

Austria provides an example of reducing the presence of adverse selection and increasing the amount of land covered by insurance, as Austrian law requires that all arable land – as opposed to specific fields - be insured in order to gain insurance coverage. The blanket approach was introduced in Austria in 1987 and formed the basis upon which the 1995 multi-peril crop insurance was provided. This trajectory could be applied to other countries to aid the transition to widespread multi-peril crop insurance.

Next Steps: Improving the use of insurance to increase resilience

One main recommendation is to place the responsibility for promoting and developing risk reduction strategies into the hands of an **external body that collaborates with insurers**. The exact nature of such an external body is difficult to determine a priori across countries; however, such an organisation can operate directly or indirectly at various levels (i.e. national, regional or city level). For instance, a national body can produce **investments in prevention strategies** or larger scale risk-reduction strategies. These actions could facilitate a national **minimum level of risk management** and insurance viability, upon which more localised bodies or agents can act. For example, **cities** can collaborate with insurers to better manage their risk beyond this minimum level imposed by the external body.

Furthermore, financial capacity for risk-reduction investments can be created by **adding a surcharge to insurance premiums into a fund** that uses the money raised to construct protection and other large-scale adaptation measures, or to **subsidise more individual-level measures**. Potential advantages of such a premium surcharge compared with financing from general taxation is that such funds are earmarked for risk reduction, and that the surcharge acts as a **signal of risk** if premiums are at least partially risk-based. This fund can be a not-for-profit management entity in which insurers, government agencies and other stakeholders are involved. Moreover, such a management entity could be mainstreamed into a country's overall climate change adaptation strategy.

Another suggestion is the improved use of **insurer's data and knowledge** in developing zoning and **building code regulations, standards and construction requirements.** Insurers often have good information on which areas are at high risk and which building-scale measures can lower risk, which is important information for government authorities to use in designing zoning and building code regulations. An advantage is that such measures are structural, which may limit information asymmetries that could arise with non-structural measures that policyholders may take only temporarily.

Finally, it could be beneficial to reconsider regulations that require policyholders to use insurance reimbursements after a disaster for reconstructing their property to the same state that it was in before the disaster occurred. Introducing such '**build back better**' requirements could allow the recovery and repair process to build risk-reduction measures directly into buildings when **awareness of the impacts of extreme weather events** is strongest.


© Droidworker | iStock

Recommendations to the stakeholder community

Promote risk awareness and reduction

Private property	Low-income (following local definitions of low income or social hardship) households struggling to afford extreme weather insurance should have this pressure eased with insurance vouchers or tax credits if they buy insurance coverage.
Private property	Minimum building standards, and build-back-better requirements, differentiated by risk levels, can be required as a standard element of insurance contracts in order to gain coverage (with a focus on measures integrated into the building).
Multi	Research with the aim of defining and quantifying resilience to support risk awareness and reduction, and a focus on how insurance can enhance the economic resilience.

Increase insurance coverage

Private property	Promote the bundling of a complete extreme weather event insurance package with private property fire insurance policies (or a similar and often purchased product).
Private property	Urge banks to require full and comprehensive insurance coverage when providing mortgage loans.
Agriculture	Redirect premium subsidies towards multi-peril (yield) crop insurance products to provide more extensive coverage. Each extreme weather event can contribute to the overall premium in line with its risk level.
Agriculture	In order to reduce the presence of adverse selection in crop insurance and only insuring the high-risk land, a farmer should be compelled to insure all arable land as part of the terms and conditions of an insurance policy.
Agriculture	Link access to wider agricultural sector subsidies (i.e. those relating to the Common Agricultural Policy (CAP) or those offered at national level) to the purchase of sufficient insurance protection in order to develop a tradition of being insured.
Agriculture	Support the use of farm income insurance by starting pilot initiatives in various Member States.

Support public-private partnerships and cross-organisational collaboration

Private property	Use a surcharge on insurance premiums (either newly introduced or redirected current taxes) to directly finance and construct risk-reduction infrastructure or to directly subsidise household level risk-reduction measures.
Private property	Create a national focal point or authority for developing and maintaining a legal framework through which extreme weather risks can be managed via a combination of risk reduction and/or transfer.
Private property	Lay down the roles and responsibilities of all the stakeholders in a national platform, focal point or authority, in a clear and transparent framework.
Agriculture	Develop an agricultural risk management association with a focus on protecting farmers against income variations due to crop yields, within a mutual or non-profit maximising organisation.
Multi	Create a working group in the European Commission enabling cross-Directorate-General collaboration, as well as coordination with national bodies.

Increase the role of cities and regions

Cities and regions	Recommend that cities assess their vulnerability in regard to insurance coverage rates, including for municipal infrastructure and extreme weather events covered, as well as reporting on how they use insurance as a mechanism for managing risks.
	Promote the use of insurance disaster loss data in the municipalities' risk-assessment data.
	Promote the active and collaborative sharing of risk, hazard and impact data across stakeholders though the standardisation of meta-data and the format of granular data that can be more efficiently and transparently shared across stakeholders productively.
	Promote the use of community rating systems for setting premiums
	Promote the spreading of risk by allowing cities to pool their insurance
	Increase capacity building with regard to insurance and climate resilience

Integration of resilience, including insurance data, in relevant policies

Member States	Introduce a requirement for flood risk management plans, national adaptation strategies and applications for loans or national or EU funds to include insurance mechanisms for managing risk that cannot be (cost-) effectively prevented in order to further mainstream insurance into national adaptation conversations.

Overall, the institutions of the European Union could actively promote the use of insurance as a tool to increase resilience against climate related extreme weather-related events. For instance, ex-ante conditionality and subsidies for insurance products could be used in the context of the European Regional and Urban Policy and the Common Agricultural Policy. Also, the European Commission could take the role of facilitating discussions and provide platforms for multi-stakeholder collaboration, promoting the use of insurance to increase resilience to weather-related events and most importantly, increase risk awareness and risk reduction.

References

- The EU Strategy on adaptation to climate change sets out the framework for strengthening Europe's resilience to the impacts of climate change. Adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimise the damage they can cause, or taking advantage of opportunities that may arise. It has been shown that well planned, early adaptation action saves money and lives later. The EU Adaptation Strategy was adopted in 2013 and is now being evaluated.
- The LIFE Programme for the Environment and Climate Change 2014-2020 is divided into two sub-programmes: environment and climate action. LIFE Climate Action supports public authorities, non-governmental organisations and private actors, especially small and medium-sized enterprises, in implementing low-carbon and adaptation technologies and new methods and approaches.
- The European Climate Adaptation Platform (Climate-ADAPT) aims to support Europe in adapting to climate change. It is an initiative of the European Commission and helps users to access and share data and information. It provides a wide range of adaptation-relevant information, for example Adaptation Support Tools with guidance for Member States on the preparation of adaptation strategies.
- The EU Covenant of Mayors for Climate and Energy brings together thousands of local and regional authorities voluntarily committed to implementing EU climate and energy objectives on their territory. New signatories now pledge to reduce CO_2 emissions by at least 40% by 2030 and to adopt an integrated approach to tackling mitigation and adaptation to climate change.
- The Global Covenant of Mayors for Climate and Energy is an international alliance of cities and local governments with a shared long-term vision of promoting and supporting voluntary action to combat climate change and move to a low emission, resilient society.
- The European Environment Agency (EEA) works on adaptation and, for example, hosts Climate-ADAPT and publishes reports on adaptation, which facilitates the dissemination and sharing of knowledge.
- The Paris Climate Agreement includes among other provisions on the global adaptation goal and reporting (see e.g. article 7). The agreement brings, for the first time, all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects. In relation to adaptation, the agreement (1) establishes the "global goal on adaptation of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change…", (2) recognises that "adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions…", and (3) includes provisions on "adaptation planning processes and the implementation of actions" and the "assessment of climate change impacts and vulnerability", etc.

Links:

CLIMA's website on adaptation:

- Website: https://ec.europa.eu/clima/policies/adaptation_en
- Selected publications:
  - → https://ec.europa.eu/clima/publications_en
  - → https://ec.europa.eu/clima/publications_en#Adapt
  - → https://ec.europa.eu/clima/sites/clima/files/docs/major_projects_en.pdf
  - → https://ec.europa.eu/clima/sites/clima/files/docs/integrating_climate_change_en.pdf
  - → https://ec.europa.eu/clima/sites/clima/files/docs/eu_strategy_en.pdf
- Selected reports:
  - → https://ec.europa.eu/clima/policies/budget/mainstreaming_en#tab-0-1

EU Adaptation Strategy:

- Communication: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52013DC0216
- Citizen's summary: https://ec.europa.eu/clima/sites/clima/files/summary/docs/adapting_en.pdf
- Adaptation Package: https://ec.europa.eu/clima/policies/adaptation/what_en#tab-0-1

LIFE:

- CLIMA's website: https://ec.europa.eu/clima/policies/budget/life_en
- LIFE Projects: http://ec.europa.eu/environment/life/project/Projects/index.cfm

Climate-ADAPT:

- Website: http://climate-adapt.eea.europa.eu/
- Adaptation support tool: http://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool

EU Covenant of Mayors:

- Website: http://www.covenantofmayors.eu
- Adaptation: http://www.covenantofmayors.eu/Adaptation.html

Global Covenant of Mayors:

- Website: https://www.globalcovenantofmayors.org/
- European Commission Press Release: http://europa.eu/rapid/press-release_IP-16-2247_da.htm

European Environment Agency (EEA):

- Website: https://www.eea.europa.eu/themes/climate-change-adaptation
- Selected reports:
  - → https://www.eea.europa.eu/publications/climate-change-adaptation-and-disaster
  - → https://www.eea.europa.eu/publications/climate-change-impacts-and-vulnerability-2016
  - → https://www.eea.europa.eu/publications/financing-urban-adaptation-to-climate-change

Paris Climate Agreement:

- http://unfccc.int/paris_agreement/items/9485.php

ML-06-17-493-EN-N

Useful resources:

European Commission Climate Action website and social media:

- ec.europa.eu/clima
- facebook.com/EUClimateAction
- twitter.com/EUClimateAction
- youtube.com/EUClimateAction
- pinterest.com/EUClimateAction

Publications Office

ISBN 978-92-79-77288-7

Annex 531

"Opening and closing remarks by Commissioner Hoekstra during plenary debate on COP28 in the European Parliament", *European Commission*, 20 November 2023

Opening and closing remarks by Commissioner Hoekstra during plenary debate on COP28 in the European Parliament

Strasbourg, 20 November 2023

Introductory remarks

Thank you madam chair, and good evening ladies and gentlemen.

COP28 marks a crucial, a truly crucial moment for global climate action.

The European Union's bar for success will be very high.

And that is because next generations are expecting us to take responsibility for their futures.

The window for action unfortunately is closing.

We can still offer these next generations a 1.5 degree future, but **it requires that the entire world does take action to reduce emissions** and prepare for the impacts of climate change.

In Dubai, parties will have to advance on all elements of the global climate agenda.

That means mitigation, adaptation, and means of implementation.

And this includes climate finance and of course, loss and damage.

Yes, we have seen important progress in the past couple of weeks, and even a breakthrough on the setup of a fund for loss and damage.

And the recent joint statements on climate action from the US and China is another welcome development.

The past six weeks, I have also met with a range of counterparts across the globe.

I spoke to some of our closest progressive partners in Africa and Latin America, and I have reached out to major economies like Brazil and China.

In each of my meetings, I stressed the need, **the absolute need to raise climate ambition.**

I have reiterated the EU's readiness to play its part.

And I emphasized that we must let ourselves be guided by science and by facts.

We know the direction of travel, we have our plans on how to get there, we simply need to speed up.

So, let me go briefly into the three areas I mentioned before: mitigation, adaptation, and means of implementation.

First: mitigation.

This year's COP28 marks the first Global Stocktake.

One thing is clear: **all countries should take meaningful action to cut emissions, particularly the world's largest emitters**.

The EU has been doing just that.

Following the adoption of nearly all Fit for 55 proposals, we have updated our NDC to provide transparency on how we plan to continue to reduce emissions.

And I have noticed in every single meeting that I had these past weeks: what we do at home is the foundation of our climate diplomacy abroad.

So I want to again thank this House, and the leaders in this House, for their work on our climate and energy legislation.

Our models show that full implementation of our policies will bring an emission reduction of around 57% by 2030.

It puts Europe firmly on track to reach climate neutrality by 2050.

To say the same about the entire world, **we need to peak fossil fuels consumption this decade and phase out unabated fossil fuels well ahead of 2050.**

We also need to stop new coal-based power capacity, triple renewable energy and double the rate of energy efficiency by 2030.

And frankly speaking we must quickly decarbonise the global power system.

Your resolution points exactly in this same direction.

It is also in line with the Global Energy Pledge that we jointly pursue with the COP28 Presidency.

Ladies and gentlemen, as the climate crisis intensifies, preparing for its impact will become unfortunately more and more important.

Our guiding star for adaptation is strengthening resilience while focusing on the lives and livelihoods of particularly those who are in the most vulnerable parts of our continent, but frankly speaking the whole world.

Through the Global Goal on Adaptation, we must strengthen adaptation planning, track progress, and mainstream climate resilience into every investment decision.

But for all these goals to be achieved, COP28 must also bring progress on aligning all financial flows with the Paris Agreement.

Strong commitments, and I say it again, **strong commitments to shift funds away from fossil fuels are particularly important**.

This can include phasing out fossil fuel subsidies that do not address energy poverty or the just transition, promoting the use of domestic carbon pricing, and agreeing international crediting rules that truly help transform financing for climate action.

In this context, we have invited different countries to join a Call to Action for Paris-aligned Carbon Markets.

Solidarity is another key component of our climate finance discussions.

The EU will continue to deliver its fair share of the 100bn goal.

A new target for after 2025 should be part of global efforts that mobilize a wide variety of sources, both public and private, to meet the goal of the Paris Agreement.

And last but certainly not least, **I remain committed to enabling the launch of the loss and damage fund at COP28.**

This needs to happen in a context where we can all feel confident that in parallel, we will see deep emissions reductions this decade.

That is and remains the best way to minimise future loss and damage.

The fund is open to contributions from all parties, and this is crucial.

Because I strongly believe that **all who do have the ability to pay, should indeed do so,** and I will continue to push for that in the conversations I'm having.

We cannot base this kind of funding on an economic division between developed and developing countries that might have made sense back in 1992.

Climate action is to be a global responsibility, and climate change is a threat that we all face.

So every country, literally every country, must do its utmost to eliminate its emissions and to defend its citizens and its future generations, from the impacts of climate change.

Thank you chair.

Concluding remarks

Grazie signora, thank you very much honourable members.

Thank you not only for your contributions, but also for being truly a formidable force for good and a formidable force for action, whenever it is the extremely important topic of climate action that is at stake.

I'm actually used, madam President, to a system where you need to address every single part of every single speaker, and that then takes on for hours and hours.

But I understand that now I need to fold that all into two to three minutes, which I will try to do.

So let me pick out a couple of points that I think are very important to take out and to underline, and I see some of the members of your Parliament already enjoying the other style form as well.

First of all, it was I think Javi López and others who once again articulated that we face an extremely difficult geopolitical situation, and that makes it even more difficult to succeed at the COP.

That is simply the reality we are facing.

Does that make the bar even harder to attain for climate action?

I think so, absolutely.

But yet at the same time, there is no alternative, there is no choice.

So let's take it as an inspiration, that even though it is difficult, **we do simply have to succeed**.

Secondly, some people were doubting whether we've already lost in terms of 1.5 degrees.

I'm slightly more optimistic.

And I think, you know, we can still keep it within reach, but I also have to admit that it is an uphill battle.

It is very difficult, and a lot more needs to be done already at the COP.

The problem is, we should have started this much earlier and we're running out of time.

We need to run roughly on the same track in terms of direction, but the speed is too low, and **we have to simply speed up**.

Third, I think it was Peter Liese, but also others who said that, on the one hand, Europe needs to take a lot of responsibility given our affluence, given where we stand in terms of emissions.

But that actually should be breached with the fact that others cannot hide behind the concepts of the past, and should need to take responsibility.

That is something I very much agree with.

And that implies that **those who have the ability to pay, should pay**. Those who pollute a lot themselves, should take that responsibility.

We see a number of countries, and I was in one of them last week, I was in China, who have made tremendous progress in terms of their economic development over the course of the last a couple of decades.

With that power, with that affluence, also comes responsibility.

So I wanted to underline that as well, because it is something on which I very much agree.

Then finally, on where we would want to put the bar.

My ambition here is truly limitless.

And yet of course the mandate, the clear mandate that I need to take as the parameters, is the one set by the European ministers.

That would mean that in Dubai, **I will advocate tirelessly for global phase-out of unabated fossil fuels**, and peaking in consumption this decade, ideally already by 2025 – because here again, time is running out.

That there is no room for new coal power, that we need to move as quickly as possible to decarbonize our power system.

That **we need to get rid of any sort of fossil fuel subsidies**, other than those addressing energy poverty or a just transition.

And I want to be crystal clear, also to avoid any misunderstandings with Mr. Eickhout in particular.

Emission abatement technologies are to be used in hard to abate sectors only, that is what they are there for.

They cannot be a way out, an escape clause for doing the hard stuff - because that is actually what is needed.

Signora Presidente, very sorry for stepping over time a bit, but I hope you will forgive me.

SPEECH/23/5904

Press contacts:

Tim McPHIE (+ 32 2 295 86 02)
Ana CRESPO PARRONDO (+32 2 298 13 25)

General public inquiries: Europe Direct by phone 00 800 67 89 10 11 or by email

Annex 532

"Climate risks in Latin America and the Caribbean – Are banks ready for the green transition?", *European Investment Bank*, September 2023

Climate risks for Latin America and the Caribbean

Are banks ready for the green transition?

European Investment Bank | Global

Climate risks in Latin America and the Caribbean

Are banks ready for the green transition?

European Investment Bank | Global

Climate risks for Latin America and the Caribbean: Are banks ready for the green transition?

September 2023

Authors
Barbara Marchitto, Joana Conde, Ricardo Santos, Carlo de Nicola, Matteo Ferrazzi, Alfredo Baldini, Rozalia Pal, Eugenio Parigi and Colin Bermingham.

This is a publication of the EIB Economics Department.
economics@eib.org
www.eib.org/economics

About the Economics Department
The mission of the EIB Economics Department is to provide economic analyses and studies to support the Bank in its operations and in the definition of its positioning, strategy and policy. The department, a team of 40 economists, is headed by Director Debora Revoltella.

For further information on the EIB's activities, please consult our website, www.eib.org. You can also contact our InfoDesk, info@eib.org.

Published by the European Investment Bank.
Printed on FSC® Paper.

pdf: QH-03-23-191-EN-N ISBN 978-92-861-5571-0 doi: 10.2867/167466

Contents

Introduction

Latin America and the Caribbean are increasingly experiencing the effects of climate change. Caribbean countries are the most exposed in the world to acute climate events, while the impacts of climate change are ever more visible in both Central and South America. No country is immune to climate change, with some risks now at "code red" level for all of humanity (IPCC, 2022), but some areas are more exposed than others. Climate change is disproportionally affecting countries in hot areas (with heat significantly reducing the productivity of labour), small island states exposed to storms and rising sea levels, and countries where climate-sensitive sectors (especially agriculture) play a large role in the economy. Moreover, in the case of low- and middle-income economies, governments and firms are generally less able to invest in adaptation and mitigation measures to reduce and protect against the effects of climate change. The combination of higher exposure to climate events and lower adaptation and mitigation capacity leaves some countries especially vulnerable.

Latin American and Caribbean countries are already paying a high price for climate change, despite contributing less than 5% of global CO_2 emissions. 2022 and the first half of 2023 alone have brought wildfires in Argentina, Chile and the Pantanal region; as well as heavy flooding in Guatemala, Peru, Bolivia, Colombia, Trinidad and Tobago, Venezuela, Honduras, Brazil, Paraguay and Ecuador; affecting 5 million people and causing over 1 000 deaths. This period has also been marked by droughts in Argentina, Uruguay, Honduras and Brazil, which are heavily reliant on agriculture. The droughts experienced in South America since 2019 are some of the worst in recent decades in terms of both extent and duration. Over the same period, tropical cyclones have hit several Central American and Caribbean countries, including Costa Rica, Guatemala, Belize and Honduras, impacting 5.8 million people (Centre for Research on the Epidemiology of Disasters, 2021).

Over the past two decades, the countries in the region have experienced as many as 1 350 natural disasters attributable to the climate, affecting more than 170 million people and causing almost 30 000 deaths. The economic damage associated with these events is estimated at over $170 billion.[1] Moreover, extreme weather events in the region are associated with an increase in the fiscal deficit of 0.8-1.1% of gross domestic product (GDP) (Delgado et al., 2021) and have various broader implications for economic and political stability.[2] Looking back further, natural disasters have tripled in frequency since the 1970s, while their costs have risen from $7.4 billion to more than $100 billion in the 2010s (Cavallo et al., 2020; Galindo et al., 2022).

Caribbean small island states are, in particular, disproportionately hard hit by extreme weather events, which are becoming both more frequent and more damaging. Of the ten countries worldwide that suffered the largest average losses per unit of GDP (in %) between 2000 and 2019, seven are Caribbean countries: Dominica (placing first), Grenada (third), The Bahamas (fourth), Puerto Rico (fifth), Antigua and Barbuda (seventh), Belize (eighth) and Haiti (tenth). Dominica, Haiti, Grenada and The Bahamas are also among the top ten countries in the world by average fatalities per 100 000 inhabitants (Germanwatch, 2021). There is no shortage of extreme weather events to list in recent years in the Caribbean, but hurricanes have historically been the natural disasters with the highest estimated economic losses. Hurricane Ian in September 2022 caused approximately $100 billion in damage (Statista, 2022).[3] The 2017 Atlantic hurricane season is considered to have been the third most destructive on record, with 17 named storms, ten hurricanes and six major hurricanes. Two of them, Hurricane Maria (total losses estimated at $69 billion) and Hurricane Irma, were both Category 5 events, the most intense on the scale (Statista, 2022). Tropical Cyclone Eta in 2020 was also particularly damaging.

1 Despite usefully providing an estimated dimension of the different climate phenomena, such data — derived from the Emergency Events Database (EM-DAT) — are largely underestimated (Centre for Research on the Epidemiology of Disasters, 2021; Jones et al., 2022) due to the underrepresentation of some climate events. This pertains in particular to information on monetary damages, and especially for lower-income countries. Moreover, these estimates are related only to first-round direct impacts, without taking into account possible second-round effects.

2 Exposure to physical climate risk can have negative implications for sovereign debt (Zenios, 2022), the cost of debt (Cevik, Tovar Jalles, 2020; Mallucci, 2020; Kling et al., 2018; Buhr et al., 2018), sovereign ratings (Standard & Poor's, 2015; Klusakab et al., 2021; Revoltella et al., 2022), fiscal sustainability (Agarwala et al., 2021), financial stability (Liu et al., 2021; Bolton et al., 2020), international trade and even political stability (Moody's Investors Service , 2016; Fitch, 2022; Volz et al., 2020). The potential impact is more evident for some small countries and those with lower capacity to bear climate change costs (Mejia, 2016; Nordhaus, 2010), but even more advanced countries are not immune to debt sustainability concerns related to climate events (Gagliardi et al., 2022).

3 This estimate includes damage in part of the Southeast United States (Florida and the Carolinas).

The damage caused by extreme and acute events represents only part of the impact of climate change in Latin America and the Caribbean. The costs related to chronic risk, connected with the gradual impact of global warming, are also relevant here. We estimate that chronic risk represents between one-third and 80% of the total physical impacts of climate change in the region, depending on the country. Caribbean countries, for example, are more exposed to acute risks, while hot Latin American countries are more affected by chronic risks. Last, but certainly not least, climate risk is also related to transition risk, which stems from policies aimed at achieving a lower-carbon economy (e.g. phasing out local coal industries).

In this paper, we start by analysing climate risks in Latin America and the Caribbean following the methodology developed by Ferrazzi et al.[4] We then expand the analysis to understand what these risks imply for the financial sector. We focus on banks, as they represent the bulk of financial intermediation in the region. The banking sector is directly affected by country-level climate risks (physical and transition risk), but the magnitude of these risks is also affected by their exposure to different economic sectors. A bank in a country with low climate risk might be highly exposed if its loan portfolio is mostly directed to high-risk sectors. Similarly, climate risk in a bank in a high-risk country might be relatively well mitigated if its exposure is concentrated in lower-risk sectors.

Are banks in Latin America and the Caribbean capable of mobilising much-needed resources for the green transition? Are they well positioned to respond to climate risks while preserving financial sector stability and providing access to finance for private sector enterprises? These are some of the questions that we try to answer in this work.

We conclude by analysing how climate-related flows to Latin America and the Caribbean compare with other regions, and the role that multilateral development banks and international financial institutions can play in filling gaps, fostering resilience and greening the financial sector. Throughout the analysis, the broader region is split into three sub-regions: Central America, South America and the Caribbean.[5]

Climate risks in Latin America and the Caribbean: A growing challenge

To assess climate risk at country level, the European Investment Bank has developed a methodology to map both physical and transition risks at country level. These risks are reflected in the EIB climate risk country scores (Ferrazzi et al., 2021) and the detailed results for Latin America and the Caribbean are shown in Appendix 1. To build the physical risk component of our climate risk assessment, we estimate the impact of climate events in gross domestic product terms (in other words, in terms of a percentage of the size of each economy) for a short-to-medium time horizon (five to ten years). The total physical risk — both acute and chronic — is given by the sum of the damage deriving from natural disasters ("acute" events such as storms, floods, droughts, etc.), production losses in agriculture (Chen et al., 2015; FAO, 2017; Feyen et al., 2019; Moody's Investors Service, 2019), the impact of sea level rise (for countries and cities exposed to the sea; Diaz, 2016), the impact on infrastructure (World Bank, 2016), the impact of heat on labour productivity (labour productivity is seriously affected when temperatures are high; Woetzel et al., 2020) and the effects of water scarcity (water is a relevant component for both agricultural production and industry; World Bank, 2016).

4 Ferrazzi et al. (2021) developed climate risk country scores — a sort of climate rating at country level — for physical and transition risk for over 180 countries, taking into account their adaptation and mitigation capacity. See Appendix 1 for the methodology.

5 Central America: Costa Rica, Guatemala, Honduras, Mexico, Nicaragua and Panama. South America: Argentina, Bolivia, Brazil, Colombia, Chile, Ecuador, Paraguay, Peru and Uruguay. Latin America includes both Central and South America. The Caribbean (excludes overseas territories): Antigua and Barbuda, The Bahamas, Belize, Dominica, Dominican Republic, Grenada, Guyana, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and Trinidad and Tobago.

Physical risk

According to the EIB climate risk country scores for physical risk, sub-Saharan Africa, the Middle East and North Africa, the Caribbean, and Pacific Island states are the most exposed to climate change worldwide. These areas, considering both acute and chronic physical risk[6], are between 2.5 and 3 times more affected than the world average, despite contributing less than 5% of global CO_2 emissions.[7] Europe and the Commonwealth of Independent States, despite being heavily affected by climate change in absolute terms, appear to be relatively better protected.[8] Figure 1 gives an overview at the global level, comparing the countries of Latin America and the Caribbean to other areas of the world, and breaking down the total impact by each factor. Acute risk — related to the damage and natural hazards component (caused by storms, hurricanes, fires, droughts, floods, etc.) — is more relevant for small island states. Chronic risks — which have to do with gradual, long-term changes due to the climate, including the impact on agriculture, sea level rise, infrastructure, labour productivity and water scarcity — are more significant for Africa and the Middle East.

Caribbean countries appear to be among those most affected by the impacts of climate change worldwide, and are specifically the most affected in terms of damage deriving from acute risk (from storms and hurricanes, for instance). Despite accounting for just 0.2% of world GDP (and 0.4% of total CO_2 emissions, or 0.2% if calculated in cumulative terms), Caribbean countries account for 10 times more in terms of the monetary cost of damage stemming from the climate, and 20 times more in terms of the number of climate events. We also estimate that for almost all the countries in the Caribbean, the cost of damage and losses deriving from climate change exceeds 1% of GDP per year. During the last two decades, ten Caribbean countries (out of the 17 under analysis) have experienced an average yearly impact due to climate of more than 2% of GDP. The cumulative effects over many years can be very significant. Five Caribbean nations figure among the top 20 globally in terms of fatalities per capita, and eight are among the top 20 countries in terms of economic losses as a share of GDP during the last two decades (World Bank, 2022).

Central and South America are also significantly affected, in line with the world average. South American states are more exposed to the impacts of climate change on agriculture. In addition to the damage to physical infrastructure (agricultural machinery, irrigation systems, livestock shelters, etc.), farmers incur losses related to lower crop yields (Chen et al., 2015; FAO, 2017; Feyen et al., 2019; Moody's Investors Service, 2019). South American states such as Guyana, Bolivia, Paraguay and Ecuador have a high share of their economy devoted to agriculture (close to or exceeding 10% of GDP), and this share is non-negligible in the bigger states as well (between 5% and 10% of GDP in Brazil, Argentina and Colombia). While Central American countries suffer more damage deriving from acute risks (storms, floods, etc.), they are also exposed to agriculture — especially Nicaragua, Honduras and Guatemala (with agriculture representing 10% of GDP or more). The gradual change in climate is also placing infrastructure under higher strain (World Bank, 2016). This effect is highly relevant for Central and South America. Less relevant, according to the EIB climate risk country scores, is the impact on labour productivity in the five- to ten-year horizon, although it is expected to be very significant in the longer term. When temperatures exceed 29 to 30 degrees Celsius, the productivity of labour for outdoor activities is increasingly affected (Woetzel et al., 2020). Water scarcity is less relevant than the other sources of physical climate risk in Central and South America, as water is available in most places and does not represent a constraint on economic production.

---

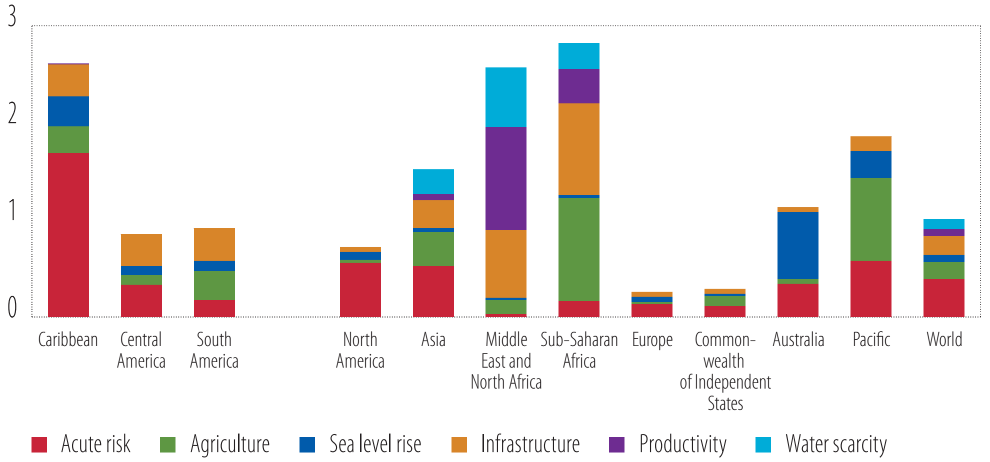
6 Physical risk can be acute, if deriving from extreme weather events and hazards: e.g. floods, landslides, extreme temperatures, storms and hurricanes, droughts or wildfires; or chronic, if related to a more gradual effect of global warming: e.g. gradual rise in sea level, lower crop yields or lower productivity due to higher temperatures. Transition risk is generated by the actions taken to move towards a lower-carbon economy, and stems from climate policies that can impact business. Transition risk can also derive from technological change, a shift in consumer preferences or litigation. See Appendix 1 for more details.

7 CO_2 emissions data show that Latin American countries contributed 4.7% of global CO_2 emissions in 2021 (0.4% for the Caribbean, 1.4% for Central America, 2.8% for South America) and 4.8% in cumulative terms (since 1970; 0.2% for the Caribbean, 1.5% for Central America, 3% for South America), according to EDGAR — the Emissions Database for Global Atmospheric Research managed by the Joint Research Centre of the European Commission (see Crippa et al., 2022).

8 Relative to the size of each economy (i.e. impact on the country's GDP), and relative to the other countries (ranked by the size of the economic impact of climate change). Thus, the assessment is not in absolute terms, but depends on the positions of other countries.

Figure 1

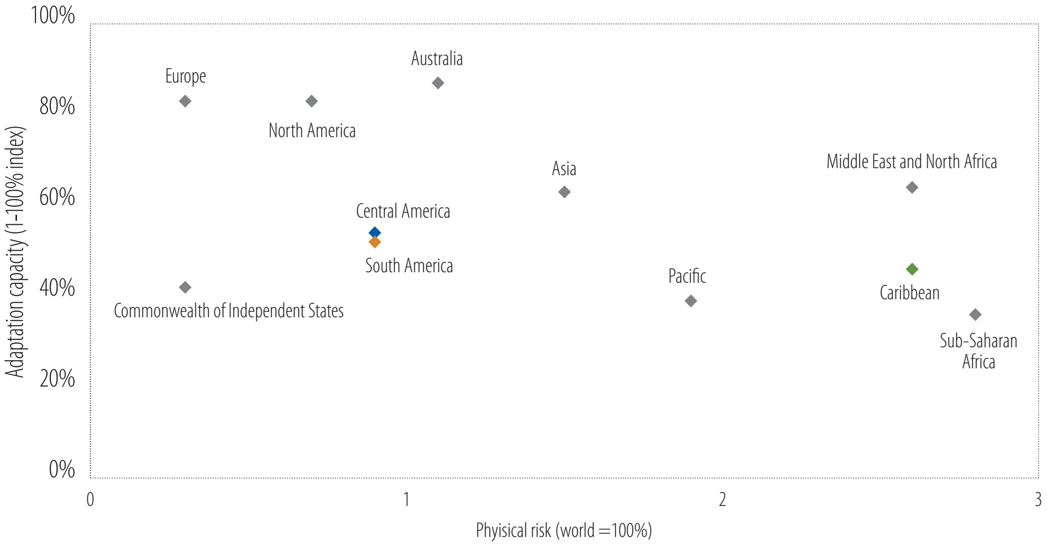
Economic impact of physical risk in the world, by component[9] (world average = 1)



Source: *EIB climate risk country scores. Note: World average is calculated as weighted average (weighted by the economic dimension of a country, i.e. nominal GDP) and is by construction equal to 1.*

Figure 2

Physical risk (before adaptation, X axis) and adaptation capacity (index, Y axis) in the world[9]



Source: *EIB climate risk country scores. Adaptation capacity is an index that can go from 0% (low adaptation capacity) to 100% (high adaptation capacity). Physical risk is gauged as prior to adaptation, with world average set equal to 1 (as in the previous chart).*

Not only are Caribbean, Pacific and sub-Saharan African countries subject to impacts from dramatic climate change, but they also have limited adaptation capacity.[10] Many of the countries most exposed to the direct physical impacts of climate change are also among those least able to invest in adaptation (bottom-right part of Figure 2). Hence, they face the double jeopardy of high exposure to physical risk and

9 In the charts and in the text in this section, the following country aggregation has been used. Caribbean: Anguilla, Antigua and Barbuda, Barbados, Aruba, Cayman Islands, Grenada, Haiti, Jamaica, Curaçao, Saint Kitts and Nevis, Dominican Republic, Dominica, Saint Vincent and the Grenadines, The Bahamas, Trinidad and Tobago, Virgin Islands (British), Saint Martin, Saint Lucia, Cuba, Puerto Rico. Central America: Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Belize, Panama. South America: Argentina, Bolivia, Brazil, Chile, Guyana, Colombia, Ecuador, Paraguay, Peru, Suriname, Uruguay, Venezuela.

10 Adaptation capacity is the ability of a system to moderate any potential damage deriving from climate change or to cope with the consequences. Examples of adaptation investments: disaster preparedness, large-scale coastal protection or stormwater management infrastructure, protection from rivers and floods, water storage, reinforcing and renovating buildings, etc. Mitigation capacity refers to actions to reduce greenhouse gas emissions (produce energy in a greener way, etc.). In short, mitigation attends to the causes of climate change, while adaptation addresses its impacts.

lower adaptation capacity (Feyen et al., 2019). High levels of public debt and weak domestic revenue sources hinder timely investment in adaptation. Some adaptation investments are largely public in nature and may be motivated by the need to avoid costs stemming from physical damage. Moreover, poor-quality housing and infrastructure amplify the human and economic impact of natural disasters. Europe, North America and Australia are less exposed to physical risks and have a greater capacity to invest in adaptation (top-right part of Figure 2). Central and South America have high exposure — similar to the world average — but do not have the same adaptation capacity as the richest countries, according to the EIB climate risk country scores.

Transition risk

Latin American and Caribbean countries face significant transition risks, but they are relatively less exposed compared to other regions of the world. Transition risks stem from the changes to our systems needed to transition towards a lower-carbon economy. They can be triggered by climate policies and affect businesses through, for instance, higher energy costs from carbon taxation or emissions cap schemes, or reduction in the market value of stranded emissions-intensive assets (Bos and Gupta, 2019). In this sense, some sectors of the economy, like those exposed to fossil fuels and those with higher emissions, may face big shifts in asset values or higher costs of doing business. The EIB's transition risk scores for countries are based on five main building blocks: (1) the level of emissions, (2) the exposure of the economy to fossil fuels; and the level of mitigation, which is built on (3) energy efficiency; (4) the deployment of renewable energy and (5) country preparedness (for more details on the methodology, see Appendix 1). The EIB transition risk country scores paint a rather different picture from the physical risk scores. It is the high-income countries — which consume a large share of the world's resources, generate significant emissions, and are most responsible for global warming — that generally face higher risks from the transition to a low-carbon world economy.

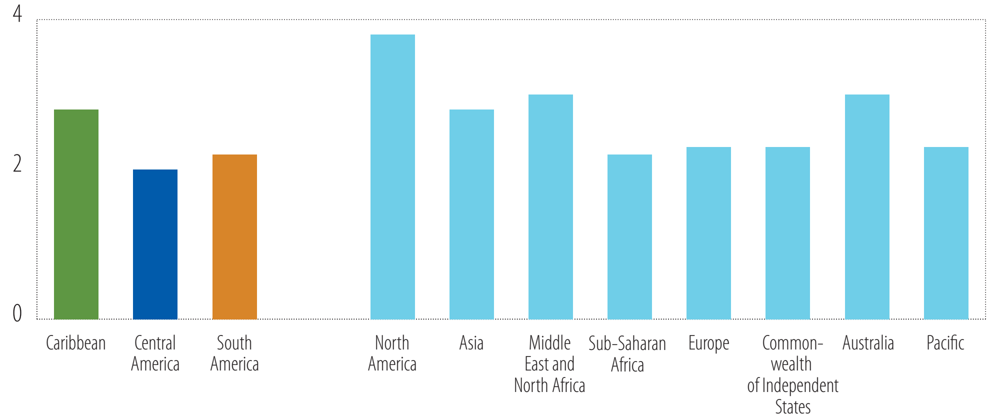
North America and Europe appear to be the most exposed to transition risk, but Caribbean countries also face high transition risk, according to the EIB climate risk country scores. As shown by Figure 3, Central America and South America have lower scores (i.e. lower transition risk) due to their lower emissions (compared to other countries) and relatively good mitigation (especially renewable energy).

One-third of the transition risk in Latin America and the Caribbean comes from the need to reduce greenhouse gas emissions, according to the EIB climate risk country scores. This is slightly less than in other parts of the world, as wealthier countries tend to be more exposed (see Figure 3). Another 25% stems from the need to deploy renewable energy (hydro, solar, wind, etc.) at sufficient scale. Several Latin American and Caribbean countries are fossil fuel exporters: Trinidad and Tobago, Suriname and Ecuador are the most dependent on fossil fuels (in terms of fossil fuel rents as a percentage of GDP, for instance), but Mexico, Argentina, Brazil, Bolivia, Colombia, Peru, Venezuela and Suriname are also reliant on revenues from fossil fuels. Governments across the region subsidised fossil fuel consumption by an estimated $115 billion in 2020. Taking into account explicit and implicit subsidies, subsidy amounts reached around 5-6% of GDP in 2020 (Parry et al., 2021). Not only are subsidies costly for governments, but they also create a perverse incentive to overconsume fossil fuel and underinvest in renewable energy. Tourism-dependent Caribbean islands may be exposed to a different source of transition risk in the medium-to-long run: the reduced appetite for/feasibility of carbon-intensive long-haul flights and distant travels may hit remote destinations in particular.[11]

11 International tourism receipts reach 70% of total exports in some Caribbean countries, while they represent 3% and 5.5% on average in Central and South America, respectively.

Figure 3

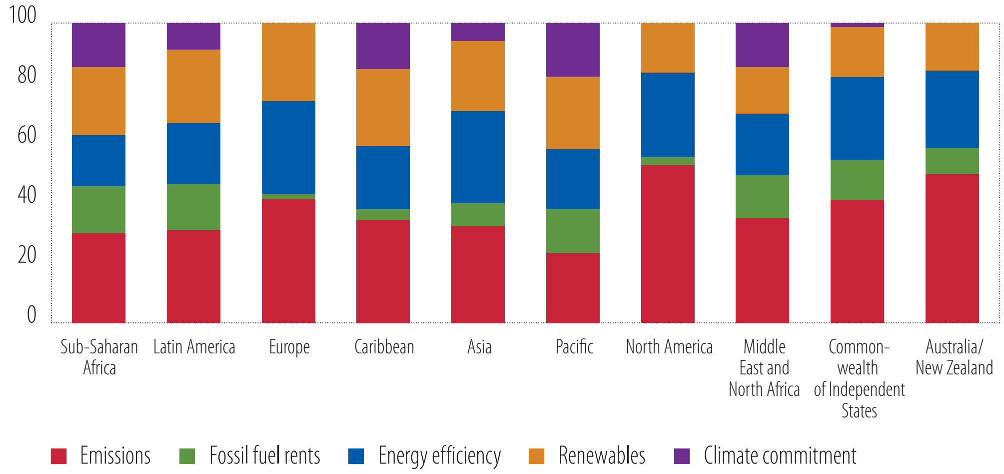
Transition risk in the world[9]



Source: EIB climate risk country scores. Note: 1 = low transition risk, 5 = high transition risk.

Figure 4

Contribution of the main components to the overall transition risk score (% on total)



Source: EIB climate risk country scores.
Note: The scores are weighted by the countries' GDPs.

Banking sectors: Are they well placed to cope with climate risks and finance the green transition?

The economies of Latin America and the Caribbean are facing a complex juncture. In 2023 and 2024, the main risks stem from adverse terms of trade effects for oil and commodity exporters, higher inflation, tightening financing conditions and the sizeable risk of a global economic recession (and particularly in the United States, the region's main trading partner). After the strong post-pandemic rebound, when GDP growth reached 7.2% in 2021, the Russian war in Ukraine has hit the region with shocks to inflation and economic growth. The International Monetary Fund (IMF, 2023a) estimates that the region's growth is set to decline from 3.9% in 2022 to 1.7% in 2023 — versus a global average of 3.4% in 2022 and 2.3% in 2023, and lower than the average for emerging and developing economies (Figure 5). A modest rebound to 3.0% is expected in 2024 as financial conditions ease, although prices of exported commodities are already sinking and growth in global trading partners is expected to weaken.

Figure 5

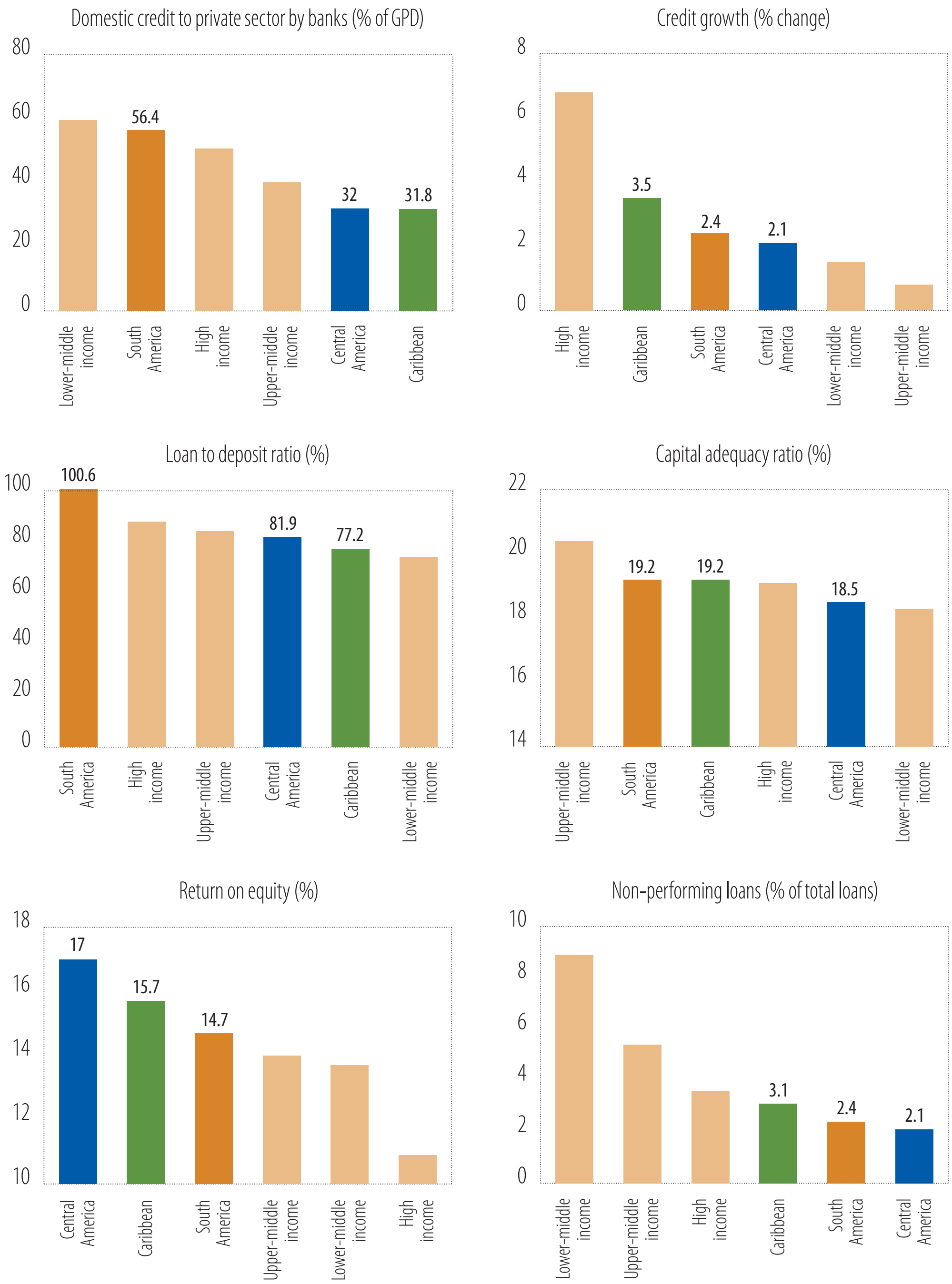
Real GDP growth (%)

Source: *IMF World Economic Outlook April 2023.*
Note: *These are GDP (2022) weighted averages per region. For the countries considered in each region, see footnote 3.*

Against the backdrop of multiple economic shocks, financial sectors have remained remarkably sound and profitable, but there are notable differences across countries and financial depth remains low compared to income peers (Figure 6). Over the last decade, most countries in Latin America and the Caribbean have avoided major banking crisis. Policy support and loan forbearance during the pandemic helped avert deterioration in asset quality, and proactive macroprudential supervision kept capital ratios at healthy levels. Furthermore, despite the ongoing economic slowdown, higher interest rates are now also supporting bank profitability. Nevertheless, despite this relatively benign aggregate picture, there are significant differences across countries, and the soundness of banking sectors in most countries is being maintained at the cost of slower credit growth. Financial depth is substantially below the average for middle or high-income countries, limiting future growth and the investment sorely needed for climate transition. In the next sections, we analyse the banking sectors of the three sub-regions in greater detail.

Figure 6

Overview of banking sector fundamentals across each sub-region and relevant income level



Source: *IMF (2022), IMF (2023a), IMF (2023b), EIB banking industry risk model. Author's calculations.*

Note: *(1) Income averages were calculated by the simple average for each variable using the set of countries within each income level category included in the World Bank's income level classification, and for which data were available. Latin American and Caribbean countries are excluded from income averages. For the domestic bank credit to the private sector (% of GDP), a total of 56 countries were included across the three income levels; for credit growth, 39; for the loan to deposit ratio, 114; and for capital adequacy ratio, return on equity and non-performing loans, 88. (2) The credit growth variable is expressed in real terms, as it has been netted out of the inflation component by using consumer price index data.*

Central America

Central America is largely dominated by Mexico, whose GDP accounts for close to 80% of the region. On average, Central America has well-capitalised and profitable financial systems, with important differences between countries. As of December 2022, the average capital adequacy ratio for the region was around 19% of risk-weighted assets. Although a healthy average, this figure is heavily influenced by Mexico, where the capital adequacy ratio is almost identical, while the other countries in the region have lower ratios. The lowest levels are in El Salvador, Panama and Honduras (all below 15%). Looking ahead, despite potential pressures on bank capitalisation, capital ratios are expected to remain relatively stable across the region due to the macroprudential regulatory measures in place. The average return on equity in Central America stands at 17%, higher than the level registered for middle-income countries in general. However, this average masks significant differences across countries. Honduras' and Guatemala's banking sectors are more profitable (with a return on equity higher than 20%) and Nicaragua's and Costa Rica's are less profitable (10% or less). Asset quality remains sound, with non-performing loan (NPL) ratios below 3% across all countries. Credit growth in real terms averaged low, at 2.1% in 2022, less than the 9-5% registered by middle-income countries. The average credit to GDP ratio in Central America is still low, at 32% (the same as Mexico), significantly lower than the 40-60% registered by middle-income countries. Still, some countries register a higher credit penetration, such as Panama (80% of GDP) and Honduras (67%).

South America

Most countries in the region benefit from robust and well-capitalised financial systems, and the region's banking sector has so far proved resilient to recent shocks. As of December 2022, the average capital adequacy ratio for the region is around a healthy 19% of risk-weighted assets. The lowest levels are in Bolivia (12.9%) and Peru (14.5%). The highest levels are in Argentina (29.6%) and Colombia (18.9%). Looking ahead, despite potential pressures on bank capitalisation, capital ratios are expected to remain relatively stable across the region. This reflects the implementation and phase-in of Basel III capital standards in Chile, Colombia and Peru, along with the generally complete implementation of most of these standards by regulators in Argentina and Brazil. In a deteriorating growth environment, the banking sector is at risk of negative spillovers from losses among corporates and small and medium-sized businesses. This would only be partially balanced by improvements in banking regulation and supervisory frameworks. Asset quality could deteriorate if the macroeconomic backdrop worsens, which could lead to a rise in non-performing loans that would have negative effects on the profitability of banks in the region. NPL ratios tend to be low on average (2.5% of total banking assets) and range from a minimum of just 1.2% in Chile to 4.1% in Peru. Credit growth to the private sector remains low in the region, with an average of 2.4% in real terms in 2022 — lagging the region's real GDP growth by 2 percentage points and that of high-income countries by 4-5 percentage points. The average credit to GDP ratio in South America is still modest, at 56.4% as of 2022. However, this ranges from high levels in Chile, Bolivia and Brazil (83%, 76% and 71.8% of GDP, respectively) to low levels in Argentina and Uruguay (10.7% and 26% of GDP, respectively).

The Caribbean

Soundness indicators suggest resilience to external shocks, but asset quality is a source of concern in some countries. As of December 2022, the capital adequacy ratio for the region stood at a healthy 19% of risk-weighted assets. The lowest levels are in Jamaica (still a safe 14.3%) and Grenada (14.8%). The highest levels are in The Bahamas (28%), Saint Vincent and the Grenadines (23%) and Haiti (21.7%). Profitability is high, driven by the largest countries. Apart from Suriname, banks' return on equity is highest (21%) in the two largest countries, the Dominican Republic and Haiti, such that the GDP-weighted average return on equity is a robust 16% for the region. However, the simple, unweighted average is a much lower 6%, which reflects large negative values in Saint Kitts and Nevis and in Dominica (-33% and -14%, respectively), and more modest values (between 2.9% and 4.4%) in other smaller countries like

Belize, Guyana, and Saint Vincent and the Grenadines. Asset quality also varies widely across countries, and non-performing loans range from a mere 1% in the Dominican Republic to 22% in Saint Kitts and Nevis. They tend to be on the high side in other countries that share the Eastern Caribbean Currency Unit (ECCU), like Dominica and Saint Lucia (both 14%). When GDP-weighted, the average NPL ratio in the region is just 3%, while the unweighted average increases to 8%.

There remains a great deal of heterogeneity in terms of banking systems, but on average financial depth in the region is low. Domestic credit to the private sector in 2022 ranged from 8% in poverty-ridden Haiti to 84% in Barbados and, although the majority of countries surpass upper-middle income peers, only a few are above high-income peers. In particular, the Dominican Republic, despite being the most diverse and dynamic economy in the region, scores fourth lowest in the region, with a modest 27%. Credit growth remained negative in Haiti as well as in most of the small countries, as these are still trying to recover from the recent pandemic and the current high inflationary environment. Suriname is a special case, as the country is trying to recover from a deep crisis that began in 2016 and led to a sovereign default during the pandemic.

Banking sector exposure to climate risk in Latin America and the Caribbean

Methodology

The approach we use to assess climate risks in the banking sector rests on two pillars: (1) each bank's vulnerability to climate risks via their portfolio exposure to various sectors of the economy, and (2) the climate risks of the country where the bank is operating. By doing so, we aim to gain a better understanding of the magnitude of the climate challenge for banks in the region and their capacity to preserve financial stability. Moving forward, financial sectors will need to become more resilient to the impacts of climate change, whether by diversifying their portfolios or by ensuring provisions against sudden events that could affect their asset quality. This in turn will ensure macroeconomic stability and adequate access to finance for private sector investment. Throughout the analysis, we distinguish between physical and transition risks.

Following the methodology developed in the forthcoming EIB Finance in Africa 2023[12], as a first step we look at banks' lending portfolios, which are underpinned by three components:

1. **Lending to non-financial corporations (NFCs) by sector of activity.** We break down banks' lending exposure to eight sub-sectors of economic activity. Under the scope of this analysis we considered, whenever available, the following sub-sectors: (1) agriculture; (2) mining; (3) tourism; (4) manufacturing and industry; (5) trade; (6) services; (7) real estate and construction; (8) other.[13]
2. **Lending to households.** As a second step, we add data on lending to households — which can encompass anything from consumption to credit cards or mortgages (depending on the country's definition).
3. **Sovereign exposures.** We consider banks' sovereign debt holdings by country.

An important departure from the methodology developed in Finance in Africa (2023) is the specific focus on tourism, which is relevant for our sample of countries, and particularly those in the Caribbean. There, the tourism sector makes an important contribution to both GDP and overall employment, which is reflected in Table 1.

12 This is a first attempt at understanding to what extent and via which channels the banking sector is exposed to physical and transition climate risks. The methodology employed is a work in progress, and this preliminary version may be enhanced in future works published by the EIB.

13 For example: Agriculture includes fishing and forestry; mining includes quarrying; services include information and communications, arts and performances, teaching, and healthcare, among others; other includes transport, deposit and storage, and utilities, among others.

Table 1

Share of employment in tourism, as percentage of total employment, 2022

Country	Share	Country	Share
Antigua and Barbuda	91	Belize	40
Saint Lucia	70	Jamaica	27
Saint Kitts and Nevis	60	Aruba	25
Grenada	53	Dominican Republic	17
The Bahamas	47	Trinidad and Tobago	9
Saint Vincent and the Grenadines	41		

Source: *World Tourism and Travel Council's 2023 Annual Research: Key Highlights.*
Note: *Only the Caribbean countries which are part of the below analysis are included in the table.*

On average across the countries in our sample, banks have 44% of their exposure to the corporate sector, 28% to the household sector and 28% to the sovereign, with significant distinctions across countries — as will be shown in greater detail.

Table 2

Climate risk levels for the NFC loan book by sector of activity and by risk type

	Agriculture	Mining	Tourism	Manufacturing and industry	Trade	Services	Real estate and construction	Other
Physical	High	High	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low
Transition	Medium-Low	High	High	Medium-High	Medium-Low	Medium-Low	Medium-High	Medium-High

Source: *European Investment Bank.*

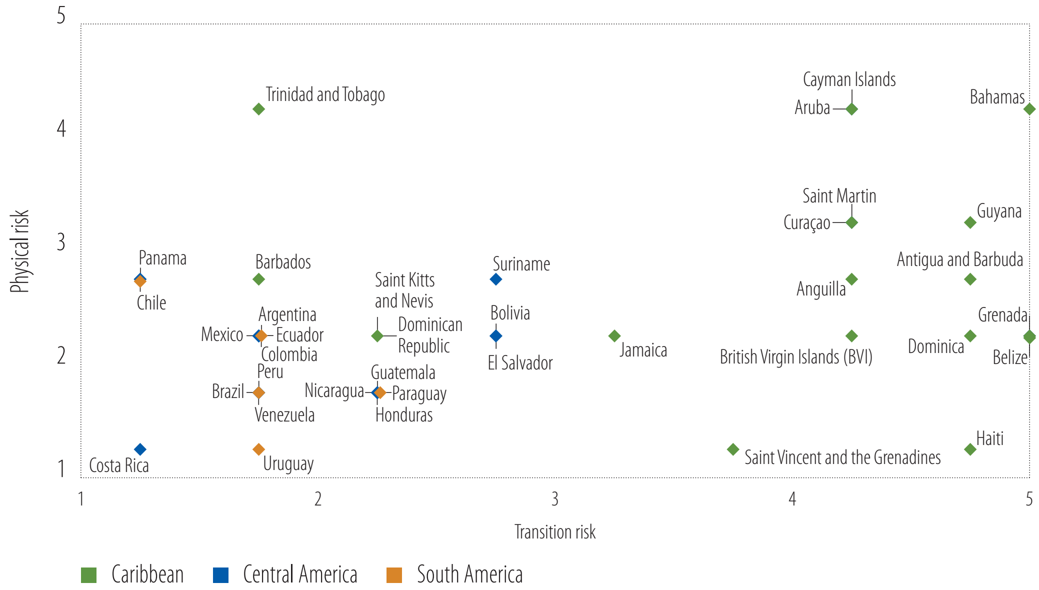
As a second step, each sector of economic activity is assigned a level of climate risk for both physical and transition risk. To move forward with a cross-sectoral and cross-country analysis, at this stage, an aggregation exercise had to be done to match the internal sectoral risk scores with the broader sectoral aggregation of non-financial corporations on their lending exposure datasets. For the most part, there is a large overlap between the two, but in some cases judgement was exercised in matching them. Ultimately, each sector is attributed a qualitative risk level, presented in Table 2, by applying a reasonable threshold.[14] Physical risk is deemed to be highest in the agriculture and mining sectors, while for transition risk there is an overlap with the mining sector, and tourism joins the list. The sovereign and household exposures are assigned their respective country climate risk scores (Figure 7).[15] The reasons for this are that, on one hand, the sovereign component has both direct and indirect exposure to the whole economy, and on the other hand, households are such a broad category that they mirror the country-level risk.

14 Overall, the quantitative scores range from 1-5. The qualitative scores may be: Low (very light green, not pictured in Table 2 and corresponding to scores < 1.5), Medium-Low (green, corresponding to scores > 1.5 and < 2.5), Medium-High (orange, corresponding to scores > 2.5 and < 3.5) and High (red, corresponding to scores > 3.5).

15 Appendix 1 provides a detailed overview of EIB climate risk scores at country level, for both climate and transition risk, including a brief explanation of the methodology.

Figure 7

EIB climate risk country scores



Source: *European Investment Bank.*

As a third step, exposures to the sovereign, households and non-financial corporations are weighted by their respective physical and transition risk scores. To be concrete, the aggregate banking climate risk (BCR) score is calculated separately for physical and transition risk as:

$$BCR_i = NFC_i w_{NFC} + S_i w_H + S_i w_S,$$

where NFC_i is the EIB non-financial corporation climate risk score for sector of economic activity i, S_i is the EIB climate risk score for country i, w_{NFC} is the weight of the banking sector's exposure to non-financial corporations, w_H is the weight of the banking sector's exposure to households and w_S is the weight of the banking sector's exposure to the sovereign. The three weights (non-financial corporation, household and sovereign exposure) are calculated by adding up the total loans or bonds extended by the banking system to each sector in local currency terms. The weights are the relative shares of the three exposures. This way, the weights add up to 100. Note that the weights are not the share of total assets, as the total assets of the banking sector are larger than the assets considered here.

Finally, after computing the aggregate banking sector climate risk scores, we take the country dimension into account by notching them up or down based on each country's level of physical or transition risk. For instance, the exposure of Luxembourg's agricultural sector to physical climate risks is entirely different to that of Haiti. Therefore, if a country is classified as having high physical risk according to the EIB climate risk scores, the sectoral physical risk scores are notched up (meaning higher risk), and vice-versa. Table 3 quantifies the magnitude of this notching exercise. Depending on the country's EIB climate risk scores (which range from 1 to 5), a corporate score can be notched up (or down) by as much as 1 (-1) — applying the full magnitude of adjustment if the country has the highest (lowest) possible risk score. With 27 countries in the present sample, this results in 54 industrial notchings (one each for physical and transition). Of these, only one has a magnitude of adjustment greater than ±0.75; the average notching is -0.1, for both physical and transition risk. This is mostly driven by South and Central American countries, which dominate the sample and belong to the lower part of the EIB climate risk scale. The final scores are on a ten-point scale between 1 and 5 where scores < 1.5 are labelled "Low", scores > 1.5 and < 2.5 are "Medium-Low", scores > 2.5 and < 3.5 are "Medium-High", and scores > 3.5 are "High".

Table 3
EIB climate risk country score and corporate score adjustments

Country Score	Adjustment	Country Score	Adjustment
1	-1.00	**3.25**	0.00
1.25	-0.75	**3.75**	0.25
1.75	-0.50	**4.25**	0.50
2.25	-0.25	**4.75**	0.75
2.75	0.00	**5**	1.00

Source: European Investment Bank.

Results

This section presents the results of the calculations of the EIB aggregate banking climate risk scores, looking into the dimensions of physical and transition risk separately. The scope of analysis includes a total of 27 countries: six from Central America, nine from South America and 12 from the Caribbean. These reflect the countries for which two important data points were readily available: data on lending exposures at an adequate level of aggregation from national central banks or regulatory bodies, and data on sovereign debt holdings by the banking sector from the International Monetary Fund's Monetary and Financial Statistics database.[16] Note that end-2022 data are used for the large majority of countries.

Sector exposures differ significantly across countries, although generally the main channel through which banks are exposed to physical and transition risk is non-financial corporations. Table 4 below shows the share of bank exposures to different sectors as a share of the total loan book. The table considers the three main sectors toward which the banking sector has exposures — non-financial corporations, households and sovereign debt. As mentioned before, non-financial corporations are split into eight further granular sectors of economic activity which, if added together, show the relative exposure of the banking sector to non-financial corporations as a whole.

Focusing solely on the loan book for non-financial corporations, Paraguay and Belize stand out as having the largest exposures to high-risk sectors, albeit from different sources.[17] Paraguay is the country with the largest exposure to overall sectoral risk (80% of total exposure), and its aggregate exposure to high-risk sectors is also the highest (29% of total exposure), with agriculture being the clear driver. Similarly, the runner-up, Belize, is a country where tourism contributes 30% of GDP, and thus the banking sector's loan book has one of the highest tourism exposures, with 11% of all lending activity being directed there.

Beyond these top two, for a further seven countries, combined exposures to high-risk sectors of economic activity are at least 9% of total relevant exposures, and highlight regional disparities. On one hand, in Latin America, Argentina, Bolivia, Ecuador, Uruguay and Honduras stand out for their exposure to agriculture which is, in aggregate, the most relevant component among lending to high-risk sectors, highlighting the prominence of physical risk in the region. Indeed, agriculture is widespread, and some countries are among the leading exporters of products like soy and maize (Argentina, Bolivia and Paraguay), sugar cane (Paraguay), coffee and palm oil (Honduras), beef and other cattle (Argentina) and fruits and vegetables, as well as products that later feed into other industries (including medium-risk sectors like manufacturing), such as cotton. On the other hand, for the remaining Caribbean countries, those with the highest exposure to high-risk sectors of economic activity are Grenada and Saint Kitts and Nevis — at 16% and 9% of all banking exposures, respectively — with lending to tourism being particularly important, in line with the country's and the wider region's economic concentration in that sector.

16 For Brazil, Paraguay, Peru and Uruguay, data were exceptionally sourced from S&P's Connect Banking dataset. Notably, no data on lending to the tourism sector are available for these countries, causing bias in the analysis.

17 As a reminder, overall they include agriculture (physical), mining (physical and transition) and tourism (transition).

Finally, it is important to note that exposure to extractive industries is fairly underrepresented in banks' loan books across Latin America and the Caribbean. Mining is the only sector of economic activity within non-financial corporations where risk is classed as High for both physical and transition risk. Still, despite several countries being heavily dependent on this sector, particularly via exports — such as Brazil (iron ore), Bolivia (silver, lead and zinc), Chile (minerals and petroleum), Argentina (lithium), Mexico (oil) or Peru (coal) — this is not reflected in a higher exposure to this sector via banks' direct lending. One reason for this could be that, in cases like Mexico, the sector is dominated by state-owned enterprises, which borrow under state guarantees directly from the treasury. In other cases, like in Brazil or Chile, the companies that operate in this sector borrow directly from foreign banks or issue debt in international markets. This implies that part of the exposure may be comprised in the sovereign exposure rather than in the sectoral one or may not even appear on domestic banks' balance sheets at all.

Risks stemming from household and sovereign exposures are in some cases also non-negligible, but there are significant differences across countries. Household exposures are largest in the Caribbean, with shares ranging from 7% in Guyana all the way up to 67% in Saint Vincent and the Grenadines. This contrasts with an average exposure to households of 24% in Latin American countries. Turning to sovereign exposures, by contrast, Nicaragua, Guyana and Argentina have the largest among the sample, ranging between 51% and 95%.

Results concerning the concentration of lending to high-risk sectors on banks' balance sheets are, on average, comparable to other regions in the world. The forthcoming Finance in Africa 2023 report shows that, on average, African countries have 6% of their loan book in high-risk sectors[18], against an average of 7% in Latin America and 8% in the Caribbean. Still, as was shown in the section above, financial sector depth is low, especially in the Caribbean, which is the sub-region most exposed to climate risk.

Another noticeable difference to sub-Saharan Africa is the non-negligible contribution of lending to extractive industries, and therefore direct exposure to physical and transition risk. As seen above, however, this is less so the case for Latin America and the Caribbean, where agriculture and tourism are the main drivers, respectively.

18 Note that in Finance in Africa 2023 the tourism sector is not considered separately, and is likely included under the service sector, which would underestimate the share of lending in high-risk sectors.

Table 4

Share of banks' balance sheet exposure by sector of economic activity and respective risk category, % of total loans, 2022

Country	Agriculture	Mining	Tourism	Manufacturing and industry	Trade	Services	Other	Real estate and construction	Corporate	Household	Sovereign	Banking sector's level of exposure to: Physical risk	Transition risk
Costa Rica	2%	0%	2%	3%	8%	12%	3%	27%	57%	26%	17%	Low	Low
Guatemala	4%	0%	1%	13%	9%	0%	15%	8%	50%	4%	46%	Medium-Low	Medium-Low
Honduras	5%	1%	3%	15%	12%	0%	15%	11%	62%	3%	34%	Medium-Low	Medium-Low
Mexico	1%	0%	2%	7%	5%	5%	2%	9%	31%	24%	44%	Medium-Low	Medium-Low
Nicaragua	0%	0%	0%	0%	3%	0%	0%	1%	4%	1%	95%	Medium-Low	Medium-Low
Panama	3%	0%	0%	6%	21%	3%	0%	9%	42%	51%	7%	Low	Medium-High
Central America	*2%*	*0%*	*1%*	*7%*	*10%*	*3%*	*6%*	*11%*	*41%*	*18%*	*41%*	*Medium-Low*	*Medium-Low*
Argentina	6%	1%	3%	8%	6%	4%	3%	1%	32%	16%	51%	Medium-Low	Medium-Low
Bolivia	8%	0%	1%	14%	11%	5%	3%	31%	73%	26%	1%	Medium-High	Medium-Low
Brazil	0%	0%	0%	5%	6%	7%	0%	1%	20%	32%	48%	Medium-Low	Medium-Low
Colombia	2%	0%	1%	8%	8%	5%	7%	10%	41%	47%	12%	Medium-Low	Medium-Low
Chile	3%	1%	0%	4%	7%	28%	4%	4%	50%	40%	10%	Low	Medium-Low
Ecuador	7%	1%	1%	12%	21%	7%	2%	5%	55%	0%	45%	Medium-Low	Medium-Low
Paraguay	29%	0%	0%	9%	18%	11%	9%	3%	80%	17%	4%	Medium-Low	Medium-Low
Peru	4%	0%	0%	14%	15%	17%	0%	8%	58%	34%	7%	Medium-Low	Medium-Low
Uruguay	13%	0%	0%	11%	12%	13%	3%	3%	54%	34%	12%	Medium-Low	Low
South America	*8%*	*0%*	*1%*	*9%*	*12%*	*11%*	*3%*	*7%*	*52%*	*27%*	*21%*	*Medium-Low*	*Medium-Low*
Antigua and Barbuda	0%	0%	8%	0%	8%	22%	4%	0%	42%	40%	18%	High	Medium-High
Bahamas	0%	0%	1%	0%	0%	1%	5%	4%	11%	56%	33%	High	High
Belize	10%	0%	11%	3%	0%	3%	11%	39%	76%	14%	10%	High	Medium-Low
Dominica	0%	1%	4%	1%	6%	20%	8%	0%	39%	31%	30%	High	Medium-Low
Dominican Republic	3%	0%	4%	6%	12%	2%	10%	23%	60%	23%	17%	Medium-Low	Medium-Low
Grenada	1%	0%	15%	2%	4%	10%	3%	0%	36%	60%	4%	High	Medium-Low
Guyana	4%	1%	1%	7%	0%	19%	2%	0%	33%	7%	59%	High	Medium-High
Jamaica	1%	0%	6%	3%	0%	9%	11%	3%	34%	46%	20%	Medium-High	Medium-Low
Saint Kitts and Nevis	0%	0%	8%	1%	5%	17%	4%	0%	35%	46%	18%	Medium-Low	Medium-Low
Saint Lucia	0%	0%	8%	2%	7%	16%	3%	0%	36%	52%	12%	Medium-High	Low
Saint Vincent and the Grenadines	0%	0%	1%	1%	6%	10%	1%	0%	19%	67%	14%	Medium-High	Low
Trinidad and Tobago	0%	1%	2%	18%	0%	24%	7%	12%	65%	11%	25%	Medium-Low	Medium-High
Caribbean	*2%*	*0%*	*6%*	*4%*	*4%*	*13%*	*6%*	*7%*	*41%*	*38%*	*22%*	*Medium-High*	*Medium-High*

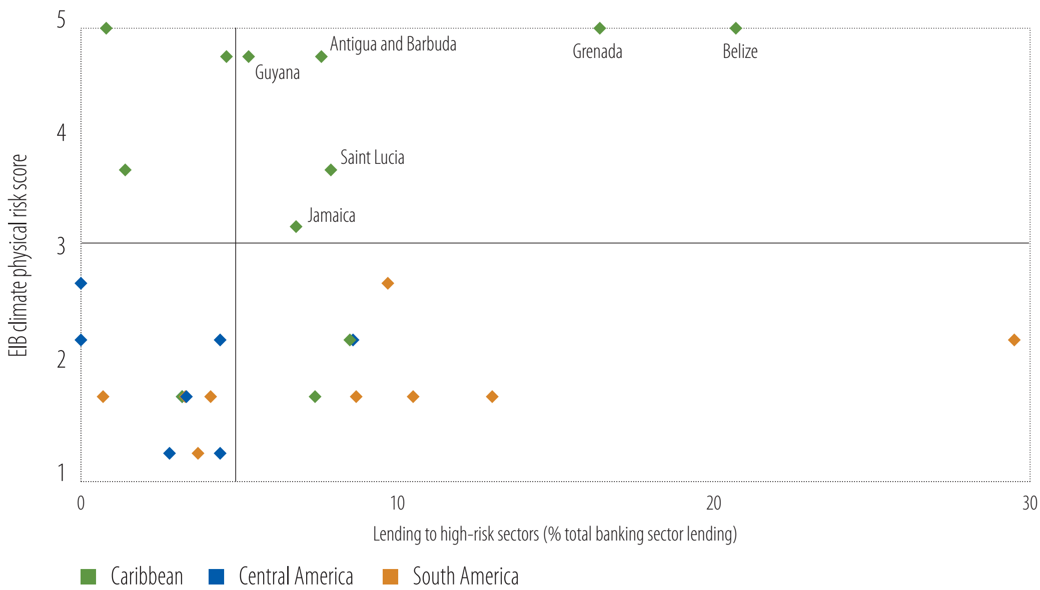
Source: *National central banks or regulatory bodies, the IMF's Monetary and Financial Statistics database, EIB non-financial corporation sectors' risk scores, EIB climate risk scores.*

Note: *(1) Year-end 2022 data for the vast majority of countries. (2) The two columns to the right distinguish each country's aggregate banking sector exposure to physical or climate risk, calculated as described in the previous section. Hence, scores < 1.5 are labelled "Low" and coloured light green; scores > 1.5 and < 2.5 are "Medium-Low" and coloured light yellow; scores > 2.5 and < 3.5 are "Medium-High" and coloured light orange; and scores > 3.5 are "High" and coloured red.*

Countries with the highest shares of lending to high-risk sectors do not, for the most part, overlap with those with the highest levels of physical climate risk identified in the EIB scoring model (Figure 8). Banking sectors in the region seem to be diversifying their loan books away from the most exposed sectors as the vast majority of countries fall in the bottom quadrants (low physical risk) as well as in the top-left one (high physical risk, low portfolio exposure). By contrast, a few Caribbean countries are in a vulnerable position with a twofold concern: high physical risk and high lending to high-risk sectors by banks. Among them are Grenada and Belize, which have the highest possible score on the scale regarding physical risk, paired with high shares of private sector lending to high-risk sectors totalling 21% and 16%, respectively, which works as an aggravating factor.

Figure 8

EIB climate physical risk score vs. share of lending to high-risk sectors



Source: EIB. Author's calculations.

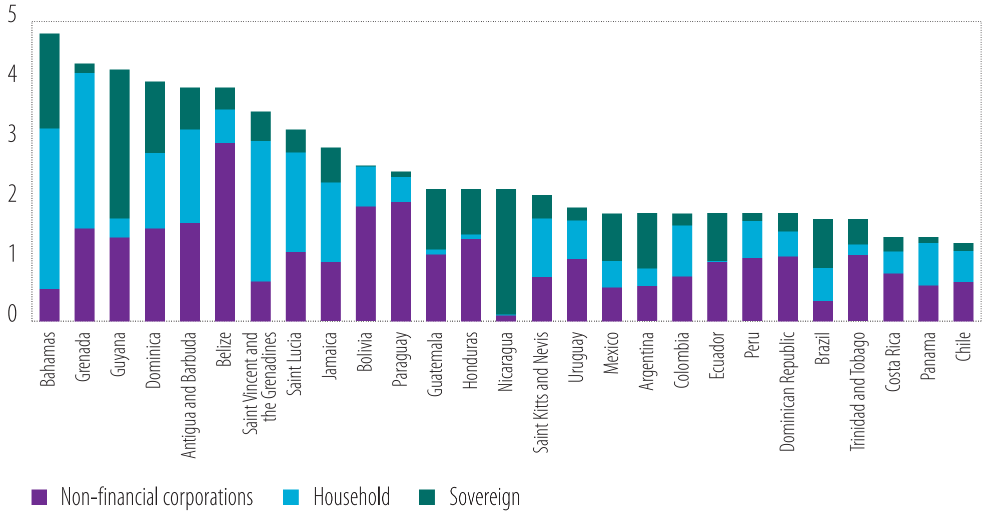
Note: The quadrants are marked by a vertical line, which is the median lending to high-risk sectors in the whole sample (4.9%); and by a horizontal line, which is the mean of the EIB physical risk scale.

The aggregate physical climate risk of the banking sector is the highest in the Caribbean, particularly in The Bahamas, Grenada and Guyana (Figure 9). The average physical climate risk exposure for the Caribbean is 3.4, which technically still qualifies as Medium-High risk (with the High bracket starting at 3.5). Central and South America follow at a significant distance, scoring 1.9 each, which instead qualifies as Medium-Low risk. Another clear conclusion from the chart is that physical risk is considerably higher in the Caribbean (clustered on the left-hand side) than in Latin America.

As for transition risk, the picture is more homogeneous (Figure 10). The average transition risk for the Caribbean is lower than for physical risk (2.5 for transition, instead of 3.4 for physical, mainly driven by acute risk) and is closely followed by Latin America, which scores 2.1 overall. The reasons for this pattern are twofold: First, EIB climate country risk scores in the region are more homogenous for transition risk; and second, some economies in Latin America are more exposed to economic sectors vulnerable to transition risk, such as mining.

Figure 9

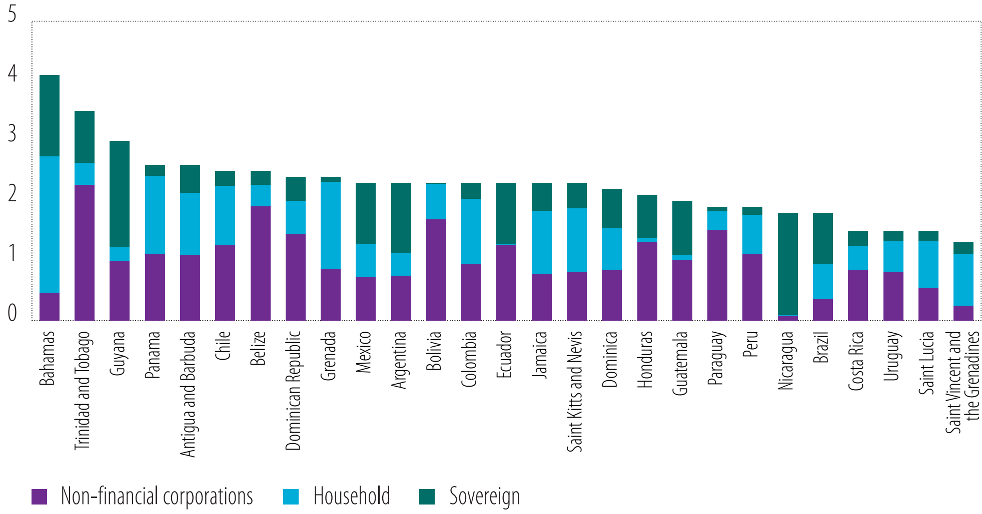
Aggregate banking sector exposure to physical risk by sector



Source: *National central banks, EIB aggregate banking exposure scores, author's calculations.*

Figure 10

Aggregate banking sector exposure to transition risk by sector

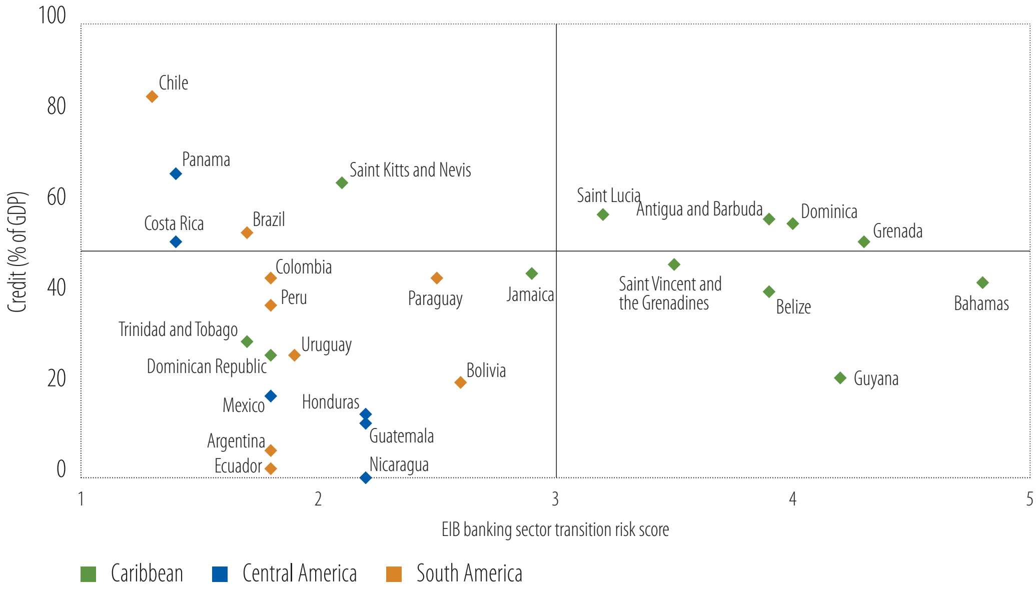


Source: *National central banks, EIB aggregate banking exposure scores, author's calculations.*

For a complete picture, the relative scale of banking sector credit exposures must also be considered. The analysis thus far has weighted climate risk based on the size of exposures, without reference to the overall size of the banking sector in each country. But when taking the overall size of the banking sector into account (Figures 11 and 12), the Caribbean countries turn out to be riskier; in particular, The Bahamas, Belize, Jamaica and Paraguay. At the other end of the spectrum, Argentina, Nicaragua, Honduras and Bolivia have both lower financial depth and lower aggregate exposure to physical risk.

Figure 11

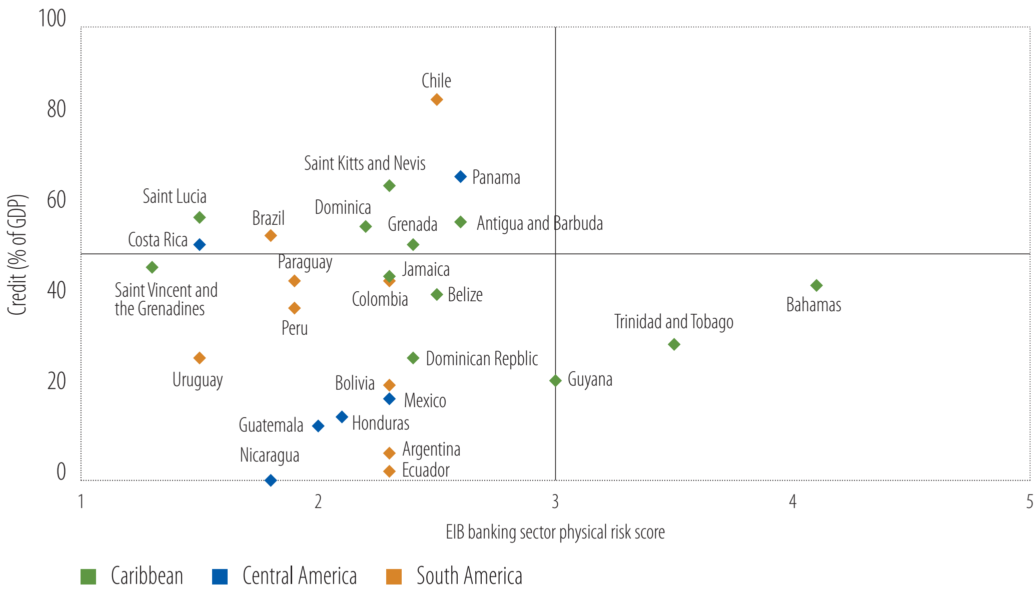
Banking sector exposure to physical risk and total banking sector credit



Source: *National central banks, EIB country and industry risk scores, author's calculations.*

Figure 12

Banking sector exposure to transition risk and total banking sector credit

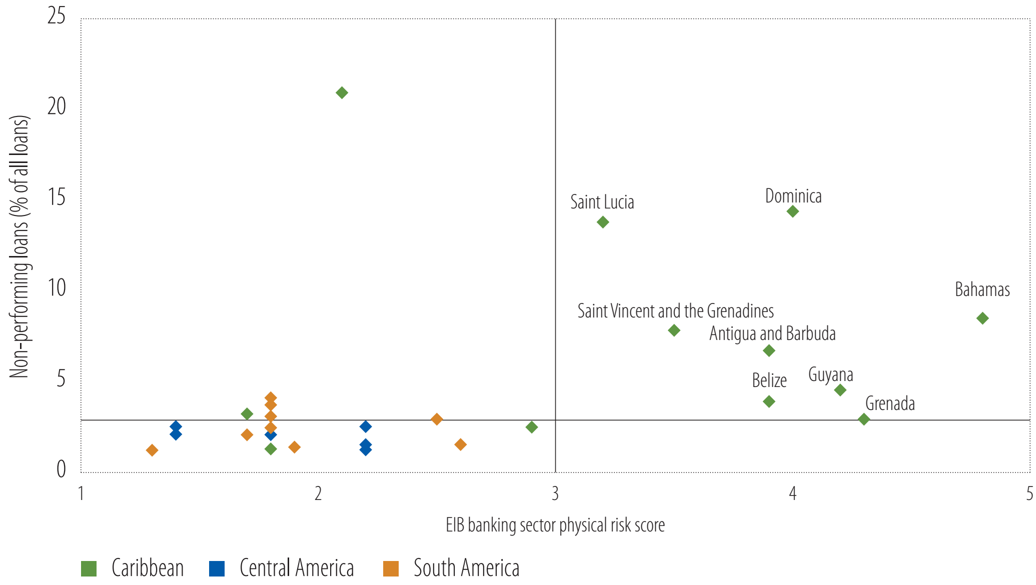


Source: *National central banks, EIB country and industry risk scores, author's calculations.*

Finally, it is also relevant to consider the current ability of banking sectors to cope with climate risks. In the previous section we assessed the soundness of banking sectors in greater detail, concluding that most financial sectors have remained remarkably sound and profitable, despite significant differences across countries. As highlighted in Figure 13, a few countries are in a delicate position, with both high risk and a high share of non-performing loans. Again, this double risk is far more prominent in the Caribbean than in the other sub-regions, notably in The Bahamas, Saint Vincent and the Grenadines, Dominica, Saint Lucia, and Antigua and Barbuda. Most of the other countries, like other regions of the world, have a relatively low share of non-performing loans (less than 5% of total loans) thanks to policy measures taken during the pandemic. Still, this situation may change, as the global macroeconomic backdrop remains highly uncertain and the impact of monetary policy tightening has yet to be fully transmitted to the real economy.

Figure 13

Non-performing loans versus aggregate banking sector exposure to physical risk



Source: *National central banks, EIB country and industry risk scores, author's calculations.*
Note: *The quadrants are marked by a horizontal line, which is the median non-performing loan share in the whole sample (2.9%); and by a vertical line, which is the mean of the EIB physical risk scale.*

Climate risks and financing: The role of international financial institutions

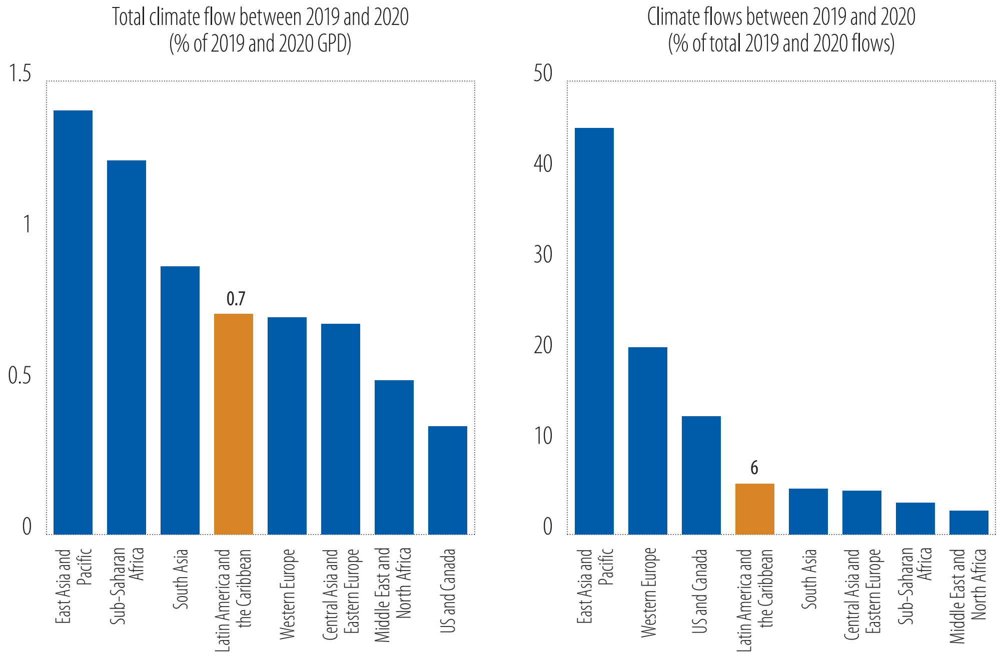
Capital flows for climate projects in the Latin America and Caribbean region have been lagging other regions, particularly given the need to overcome physical risks in Caribbean countries (Figure 14). Against this backdrop, and given the risks faced by the banking sectors in these countries, international financial institutions and multilateral development banks have a major role to play. In recent years, there has been more capital flowing toward climate projects globally. The Climate Policy Initiative (CPI, 2022a) reports that in the ten years between 2011 and 2020, climate finance doubled to reach $653 billion globally on average across 2019/2020, based on an annual growth rate over the decade of around 7%. Initial estimates for 2021 from the Climate Policy Initiative indicate that total climate flows are in the region of $850-940 billion, representing a sharp increase in growth despite the impact of the pandemic.

At the global level, climate finance is dominated by mitigation financing, which accounts for about 90% of investment. Over the last decade, about 70% of this mitigation finance has gone toward renewable energy generation, although low-carbon transport is a significant growth area. There is also a relatively even split between public and private sources. However, the growth rate of public funding has been significantly higher over the past ten years, as its starting point was notably lower.

Latin America and the Caribbean countries receive a relatively small share of global climate finance — only around 6% of the total in 2019 and 2020 (Figure 1). Global climate flows are dominated by East Asia and the Pacific, ($563 billion, or 43% of total flows) due to the presence of China in the region, followed by Western Europe and North America (20% and 13%, respectively). By contrast, climate finance in the Middle East and North Africa totalled $32.6 billion over 2019/2020 (2% of the global total), while sub-Saharan Africa saw $43.8 billion of climate investment (3% of the global total). In addition, as a share of GDP, climate flows to Latin America and the Caribbean lag other developing economies in Asia and even sub-Saharan Africa.

Figure 14

Climate flows in the sub-regions



Source: Climate Policy Initiative, Global Landscape data; author's calculations.

As shown in this paper, the Caribbean is more exposed to climate risk than other parts of Latin America and the Caribbean, with banks' aggregate exposure for both physical and transition risk at Medium-High. In addition, the banking sectors in some Caribbean countries are also in a weaker position to finance the climate transition. Central and South America follow the Caribbean at a significant distance and are classified as Medium-Low for both physical and transition risk, with banking sectors also exhibiting more ability to cope with future losses. Nevertheless, this aggregate snapshot masks significant differences across countries. As the potential damage from climate change becomes more evident and the economic backdrop deteriorates, some of the less risky countries may migrate to the higher risk category, with a reduction in their capacity to finance climate transition.

Against the backdrop of considerable financing needs, the international financial community and public development banks have an important role to play in supporting both public and private green investments by providing long-term, patient funding at affordable rates and sharing part of the risks. By doing so, they spread the positive externalities stemming from climate change mitigation investments, generating societal benefits that are not necessarily internalised in financial returns.

Multilateral development banks and international financial institutions can also provide technical assistance, identify market gaps, and help shape new markets and tools. Through loan screening and lending activities, development banks can provide market intelligence about the existing challenges and opportunities, offering guidance in the design of development policies and facilitating their implementation. Where markets for certain kinds of technology or investment activity are underdeveloped or absent, they can act to overcome information barriers and the "wait and see" attitude of would-be investors, to help create those markets (Mazzucato and Penna, 2016). The emergence of the global green bond market, kicked off by the EIB's inaugural Climate Awareness Bond in 2007, is a clear example of this. Nurtured by the early issuance activity of the EIB and other multilateral development banks, total issuance now exceeds $1 trillion. Addressing information barriers and transparency issues has proved critical in this, both to give investors confidence and to guard against greenwashing.

The EIB has a long track record of financing in the region, with a focus on climate resilience. Since the EIB began investing in Latin America in 1993, it has financed over 150 projects in 15 countries, providing around €13 billion. Its activities in the Caribbean began in 1978, where it has granted over €2 billion in financing for over 220 operations. In 2022, almost 80% of the operations signed in the region were for climate mitigation and adaption projects. This is in line with the EIB's Paris alignment strategy and the Bank's commitment to support €1 trillion of climate action investment worldwide by 2030.

A strong supporter of international financial coordination, the EIB has joined forces with other international financial institutions to address the challenges posed by climate change. For instance, the EIB is piloting the use of climate resilient debt clauses with other multilateral development banks. These innovative contractual clauses will give sovereign borrowers in Least Developed Countries and Small Island Developing States the option to defer debt service for a limited period in cases of certain defined emergencies caused by climate change and natural catastrophes. This way, the risk of debt distress as a direct consequence of natural disaster can be mitigated. Although the concept of climate resilient debt clauses is not new, they have been rare so far and the EIB initiative to offer them now is a key element of the European Union's response to the calls from the Bridgetown Initiative. The ultimate impact of these clauses will depend strongly on the number of creditors participating, so a joint and coordinated effort is important.

Building on the Resilience and Sustainability Facility with the International Monetary Fund, the EIB is also working closely with other international financial institutions and public development banks to scale up climate finance and crowd in private climate investment to build climate resilience, including in several Latin American and Caribbean countries. The groundbreaking partnership is part of ongoing efforts by the international community to reshape the global climate finance architecture. This includes moving beyond small-scale projects to significant long-term investments that leverage existing mechanisms to facilitate public-private partnerships and attract private sector investments. Taking the specific needs of individual countries into account, our joint efforts will build on a three-pronged approach to address challenges triggered by climate change combining policy reforms, capacity development initiatives, and financing arrangements.

References

Agarwala, M., Burke, M., Klusak, P., Mohaddes, K., Volz, U. and Zenghelis, D. (2021). "Climate change and fiscal sustainability: Risks and opportunities." Bennett Institute for Public Policy, University of Cambridge.

Bamber, J.L., Oppenheimer, M., Kopp, R.E., Aspinall, W.P. and Cooke, R.M. (2019). "Ice sheet contributions to future sea-level rise from structured expert judgment." *PNAS*, Volume 116 (23), pp. 11195-11200. Available at: https://doi.org/10.1073/pnas.1817205116.

Bolton, P., Despres, M., Pereira Da Silva, L.A., Samama, F. and Svartzman, R. (2020). "The green swan: central banking and financial stability in the age of climate change." Bank for International Settlements.

Bos, K. and Gupta, J. (2019). "Stranded assets and stranded resources: Implications for climate change and global sustainable development." *Energy Research and Social Science*, Volume 56, 101215. Available at: https://www.sciencedirect.com/science/article/pii/S2214629618305383.

Buhr, B., Volz, U., Donovan, C., Kling, G., Lo, Y.C., Murinde, V. and Pullin, N. (2018). "Climate Change and the Cost of Capital in Developing Countries." Imperial College London, SOAS University of London, UN Environment.

Cavallo, E.A., Powell, A., and Serebrisky, T. (2020). "From Structures to Services: The Path to Better Infrastructure in Latin America and the Caribbean." Inter-American Development Bank.

Centre for Research on the Epidemiology of Disasters (2021). Missing data on economic losses variables from EM-DAT, Issue No. 63.

Cevik, S., Tovar Jalles, J. (2020). "This Changes Everything: Climate Shocks and Sovereign Bonds." IMF Working Papers.

Chen, C., Noble, I., Hellmann, J., Coffee, J., Murillo, M. and Chawla, N. (2015). "University of Notre Dame Global Adaptation Index: Country Index Technical Report." Available at: https://gain.nd.edu/our-work/country-index/.

Climate Policy Initiative (CPI) (2022). "Global Landscape of Climate Finance 2021 database." Available at: https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2021/

Crippa M., Guizzardi, D., Banja, M., Solazzo, E., Muntean, M., Schaaf, E., Pagani, F., Monforti-Ferrario, F., Olivier, J.G.J., Quadrelli, R., Grassi, G., Rossi, S., Oom, D., Branco, A., San-Miguel, J. and Vignati, E. (2022). "CO2 emissions of all world countries - 2022 Report." EUR 31182 EN, Publications Office of the European Union, Luxembourg, ISBN: 978-92-76-55802-6, doi: 10.2760/07904, JRC130363.

Delgado, R., Eguino, H. and Lopes, A. (2021). "Política fiscal y cambio climático: experiencias recientes de los ministerios de finanzas de América Latina y el Caribe." Inter-American Development Bank.

Diaz, D.B. (2016). "Estimating global damages from sea level rise with the Coastal Impact and Adaptation Model (CIAM)." *Climatic Change*, Volume 137, pp. 143-156. Available at: https://doi.org/10.1007/s10584-016-1675-4.

European Investment Bank (2020). "EIB Group Climate Bank Roadmap 2021-2025." European Investment Bank, Luxembourg. Available at: https://www.eib.org/en/publications/the-eib-group-climate-bank-roadmap.

Ferrazzi, M., Kalantzis, F. and Zwart, S. (2021). "Assessing climate change risks at the country level." European Investment Bank Working Paper 2021/03.

Feyen, E., Utz, R., Zuccardi Huertas, I., Bogdan, O. and Moon, J. (2019). "Macro-Financial Aspects of Climate Change." Policy Research Working Paper No. 9109. World Bank, Washington DC. Available at: https://openknowledge.worldbank.org/handle/10986/33193.

Fitch (2022). "Political Risks and Climate Change: Where Are the Flashpoints?" Special Report, Long Reads.

Food and Agriculture Organization of the United Nations (FAO) (2017). "The impact of disasters and crises on agriculture and food security." Food and Agriculture Organization, Rome.

Gagliardi, N., Arévalo, P. and Pamies, S. (2022). "The Fiscal Impact of Extreme Weather and Climate Events: Evidence for EU Countries." European Commission Discussion Paper 168.

Galindo, L.M., Hoffman, B. and Vogt-Schilb, A. (2022). "How Much Will It Cost to Achieve the Climate Goals in Latin America and the Caribbean?" Inter-American Development Bank, IDB Working Paper Series, No. IDB-WP-01310.

Germanwatch (2021). Global Climate Risk Index 2021. Available at: www.germanwatch.org/en/cri.

Hochrainer-Stigler, S. (2006). "Macroeconomic Risk Management against Natural Disasters". Deutscher Universitaets-Verlag, Wiesbaden.

IMF (2022). "Financial Soundness Indicators Database." Washington, DC. Available at: Financial Soundness Indicators - FSIs Home - IMF Data.

IMF (2023a). "World Economic Outlook Database: April 2023 edition". Washington, DC. Available at: World Economic Outlook Database (imf.org)

IMF (2023b). "Global Financial Stability Report – Financial Soundness Indicators Database". Washington, DC. Available at: Global Financial Stability Report, April 2023 (imf.org)

IPCC (2019). "IPCC Special Report on the Ocean and Cryosphere in a Changing Climate" [Pörtner, H.-O., Roberts, D.C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B. and Weyer, N.M. (eds.)]. Cambridge University Press, Cambridge, United Kingdom. Available at: https://doi.org/10.1017/9781009157964.

IPCC (2022). "Climate Change 2022: Mitigation of Climate Change, Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change." Available at: https://www.ipcc.ch/report/ar6/wg3/.

Jones, R.L., Guha-Sapir, D. and Tubeuf, S. (2022). "Human and economic impacts of natural disasters: can we trust the global data?" *Nature*.

Kling, G., Lo, Y.C., Murinde, V. and Volz, U. (2018). "Climate Vulnerability and the Cost of Debt." Centre for Global Finance, Working Paper Series No. 12.

Klusakab, P., Agarwalabc, M., Burkeab, M., Kraemerde, M. and Mohaddesf, K. (2021). "Rising Temperatures, Falling Ratings: The Effect of Climate Change on Sovereign Creditworthiness." Bennett Institute Working Paper, Cambridge University.

Liu, Z., Sun, H. and Tang, S. (2021). "Assessing the impacts of climate change to financial stability: evidence from China." *International Journal of Climate Change Strategies and Management*, Volume 13, No. 3.

Mallucci, E. (2020). "Natural Disasters, Climate Change, and Sovereign Risk." Board of Governors of the Federal Reserve System, Washington, International Finance Discussion Papers (IFDP).

Mazzucatto, M. and Penna, C. (2016). "Beyond Market Failure: The Market Creating and Shaping Role of State Investment Banks." *Journal of Economic Policy Reform*, Volume 19(4), pp. 305-326.

McMichael, C., Dasgupta, S., Ayeb-Karlsson, S. and Kelman, I. (2020). "A review of estimating population exposure to sea-level rise and the relevance for migration." *Environmental Research Letters*, Volume 15(12), p. 123005.

Mejia, S.A. (2016). "Gone with the Wind; Estimating Hurricane and Climate Change Costs in the Caribbean." IMF Working Papers 16/199, International Monetary Fund.

Moody's Investors Service (2019). "General principles for assessing environmental, social and governance risks."

Moody's Investors Service (2016). "How Moody's Assesses the Physical Effects of Climate Change on Sovereign Issuers."

Nordhaus, W.D. (2010). "The Economics Of Hurricanes And Implications Of Global Warming," *Climate Change Economics* (CCE), Volume 1 (01), pp. 1-20.

NGFS (Network for Greening the Financial System) (2020). *NGFS climate scenarios for central banks and supervisors*. Available at: https://www.ngfs.net/en/ngfs-climate-scenarios-central-banks-and-supervisors.

Parry, I. et al. (2021). "Still Not Getting Energy Prices Right: A Global and Country Update of Fossil Fuel Subsidies." IMF Working Paper WP/21/236.

Revoltella, D., Bending, T., Santos, R. and Zwart, S. (2022). "Assessing climate risks for long-term investments and the role of multilateral development banks." *Scaling Up Sustainable Finance and Investment in the Global South*, CEPR.

Roson, R. and Sartori, M. (2016). "Estimation of climate change damage functions for 140 regions in the GTAP9 database." Available at: https://ssrn.com/abstract=2741588

Standard & Poor's (2015). "The Heat Is On: How Climate Change Can Impact Sovereign Ratings." Standard & Poor's Ratings Services, McGraw Hill.

Statista (2022). "Costliest natural disasters based on estimated overall losses in the Caribbean between 2000 and 2022." Available at: www.statista.com/statistics/1071365/caribbean-losses-due-to-natural-disasters/.

Volz, U., Beirne, J., Ambrosio Preudhomme, N., Fenton, A., Mazzacurati, E., Renzhi, N. and Stampe, J. (2020). "Climate Change and Sovereign Risk." London, Tokyo, Singapore, Berkeley: SOAS University of London, Asian Development Bank Institute, World Wide Fund for Nature Singapore, Four Twenty Seven.

Woetzel, J., Pinner, D., Samandari, H., Engel, H., Krishnan, M., Boland, B. and Powis, C. (2020). "Climate risk and response: Physical hazards and socioeconomic impacts." McKinsey Global Institute. Available at: https://www.mckinsey.com/business-functions/sustainability/our-insights/climate-risk-and-response-physical-hazards-and-socioeconomic-impacts.

World Bank (2016). "Private Sector Investment in Climate Adaptation in Developing Countries: Landscape, Lessons Learned and Future Opportunities." World Bank, Washington DC.

World Bank (2022). "A Roadmap For Climate Action In Latin America And The Caribbean." World Bank Group 2021-2025.

World Tourism and Travel Council (2023). "Annual Research: Key Highlights." Available at: Travel & Tourism Economic Impact | World Travel & Tourism Council (WTTC).

Zenios, S.A. (2022). "Understanding the climate risks to sovereign debt: From data to models." Prepared for the Workshop of the European Fiscal Board Brussels.

Appendix 1: The European Investment Bank climate risk country scores

To better understand and monitor climate risk at the country level, the European Investment Bank (EIB), as part of various activities related to the EIB Group Climate Bank Roadmap (European Investment Bank, 2020) and the European Green Deal, developed a climate risk methodology to map climate-related risks at the country level. These risks are reflected in the European Investment Bank climate risk country scores (Ferrazzi et al., 2021). The scores are a tool to help understand the relative climate risks faced by countries, as well as the environmental and policy conditions faced by firms in each country. They can also help to identify mitigation and adaptation priorities and related financing needs.

For each country, two main types of risks are taken into account: (1) physical risk covers the impacts of the changing climate, including the risk of natural disasters (acute risk), as well as more gradual changes (chronic risk); and (2) transition risks are policy and regulatory risks driven by the introduction of stringent climate policies to help countries achieve carbon neutrality in line with the Paris Agreement goals.

The physical risk scores are based on an estimate of the total annual burden each country faces in terms of damage, costs and losses (as a percentage of GDP) related to climate change. The scores are composed of the following building blocks:

- Acute risks of extreme weather events related to hydrological risks (floods and landslides), meteorological risks (extreme temperatures, fog, storms) and climatological risks (droughts, wildfires).
- Losses deriving from the impact of disasters on agriculture. On top of the damage to physical infrastructure (agricultural machinery, irrigation systems, livestock shelters, etc.), farmers incur losses related to lower crop yields (Chen et al., 2015; FAO, 2017; Feyen et al., 2019; Moody's Investors Service, 2019).
- Chronic risks arising from long-term and gradual shifts in climate patterns (Feyen et al., 2019; NGFS, 2020; Roson and Sartori, 2016), namely:
  - » The impact of sea level rise, which is itself the result of melting glaciers and ice sheets (Bamber et al., 2019; Diaz, 2016, IPCC, 2019; McMichael et al., 2020).
  - » The impact on the quality of infrastructure (World Bank, 2016). Just as natural disasters damage infrastructure, gradual changes in climate can place infrastructure under higher strain as well, making upgrades necessary and increasing maintenance costs.
  - » The impact of higher temperatures on productivity: the increase in temperatures beyond certain levels is expected to reduce the productivity of workers (Woetzel et al., 2020).
  - » The impact of water scarcity (World Bank, 2016). Water has an economic impact, as it is needed in agriculture (70% of water is used for the irrigation of land), industry and cities.

In addition, the physical risk score incorporates an assessment of each country's capacity to adapt to climate change. Fiscal revenues and sovereign risk ratings are used as a proxy of each country's financial capacity to adapt to climate change, while governance indicators and the level of human development are used as indicators of institutional capacity. For these reasons, developed countries are better able to cope with the impacts of natural disasters, while developing countries are suffering severe consequences (Hochrainer-Stigler, 2006).

In a similar way, the transition risk scores are based on an assessment of a country's exposure to the economic changes caused by the global climate transition, and on its capacity to reduce the negative impacts of that exposure (mitigation capacity). Countries can mitigate transition risks by taking action to limit or reduce greenhouse gas emissions. The long-term economic impacts of the climate transition will be lower for countries that can swiftly shift to a lower-carbon development model.

The transition risk scores are based on:

- Revenues stemming from the fossil fuel business. These are expected to decline in the future due to stricter climate policies and changing consumer preferences.
- Greenhouse gas emissions performance. Higher emissions imply higher costs in the future as a result of more stringent climate policies.
- Mitigation capacity, which has three dimensions:
  - » Performance in deploying renewable sources of energy.
  - » Performance in implementing energy efficiency improvements.
  - » The level of commitment to tackling climate change, based on the nationally determined contributions each country has set under the Paris Agreement.

Based on the economic literature and an econometric analysis, these different components are given appropriate weights to create a composite indicator that reflects the transition risk country score. In addition, when assessing the performance of emissions, energy efficiency improvements and renewables deployment, the scores consider (1) what the countries have achieved in the recent past, (2) where they stand currently and (3) how far they are from the global optimal standard.

Table 1

EIB climate risk country scores

Latin America and the Caribbean climate risk country scores			
Country	**Region**	Physical risk	Transition risk
Anguilla	Caribbean		
Antigua and Barbuda	Caribbean		
Barbados	Caribbean		
Aruba	Caribbean		
Cayman Islands	Caribbean		
Grenada	Caribbean		
Haiti	Caribbean		
Jamaica	Caribbean		
Curaçao	Caribbean		
Saint Kitts and Nevis	Caribbean		
Dominican Republic	Caribbean		
Dominica	Caribbean		
Saint Vincent and the Grenadines	Caribbean		
The Bahamas	Caribbean		
Trinidad and Tobago	Caribbean		
Virgin Islands (British)	Caribbean		
Saint Martin	Caribbean		
Mexico	Central America		
Guatemala	Central America		
El Salvador	Central America		
Honduras	Central America		
Nicaragua	Central America		
Costa Rica	Central America		
Belize	Central America		

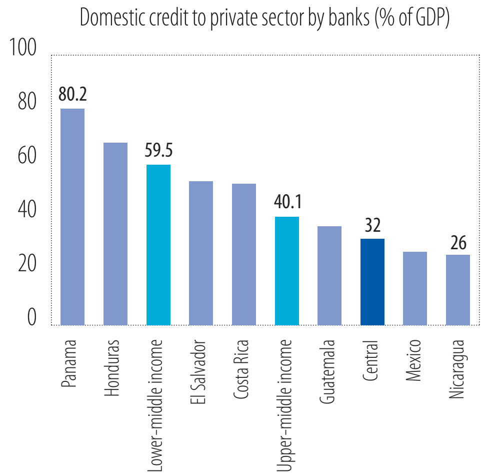
Latin America and the Caribbean climate risk country scores

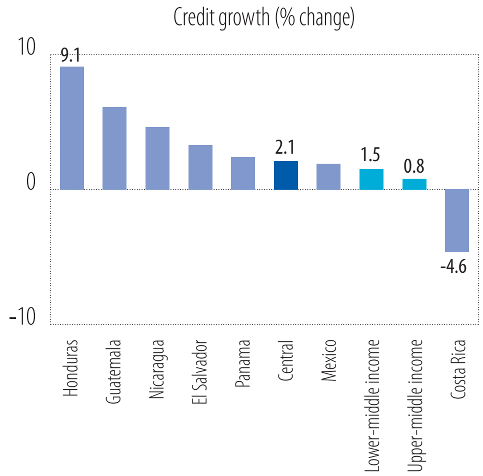
Country	Region	Physical risk	Transition risk
Panama	Central America		
Argentina	South America		
Bolivia	South America		
Brazil	South America		
Colombia	South America		
Ecuador	South America		
Paraguay	South America		
Peru	South America		
Uruguay	South America		
Venezuela	South America		
Chile	South America		
Guyana	South America		
Suriname	South America		

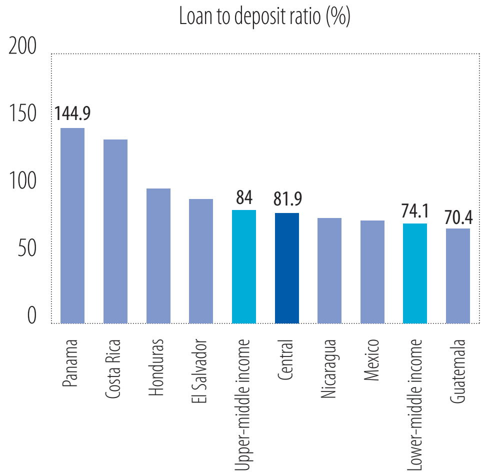
Source: *European Investment Bank.*
Note: *The different colours signal the level of climate risk for each country, for both physical and transition risk, from green (low risk) to red (high risk), according to the EIB climate risk country scores (Ferrazzi et al., 2021).*

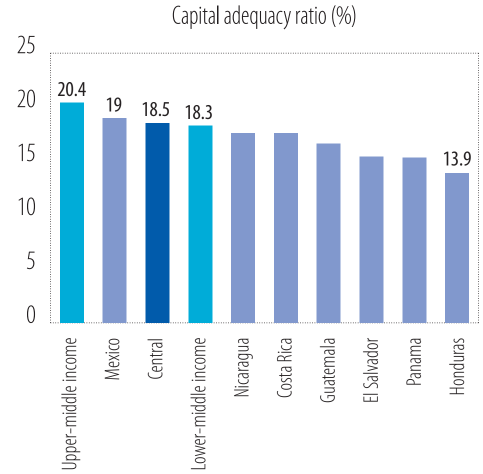
Appendix 2: Banking sector fundamentals – cross-country analysis by sub-region

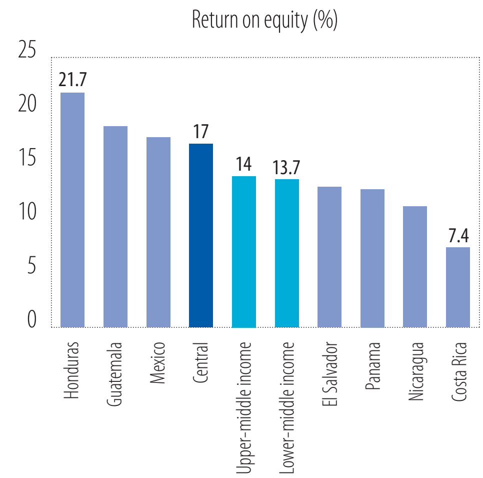
Latin America – Central

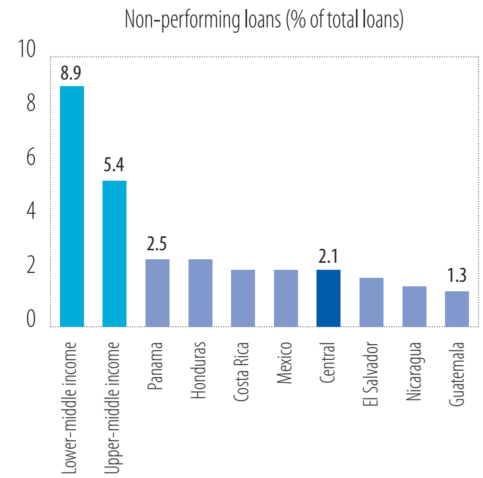






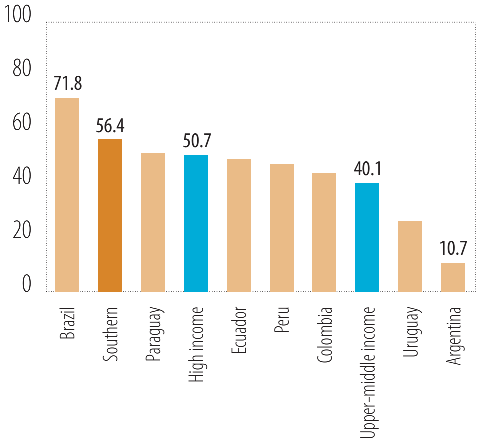




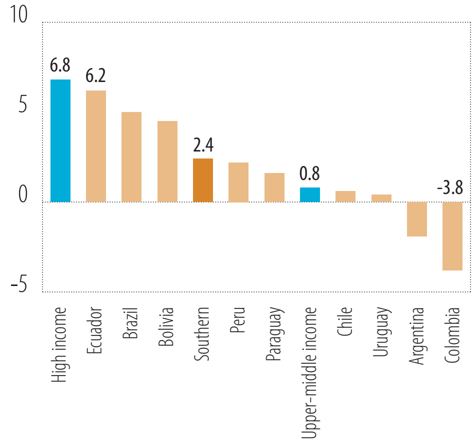


Latin America – South

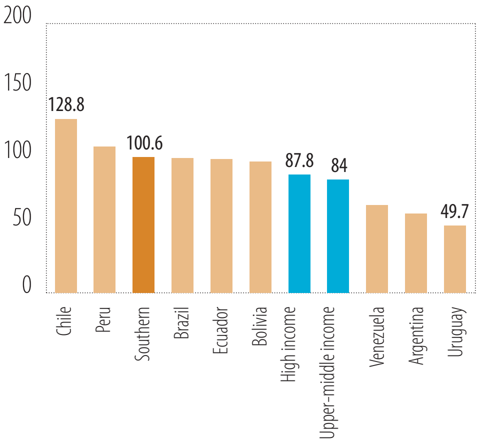
Domestic credit to private sector by banks (% of GPD)



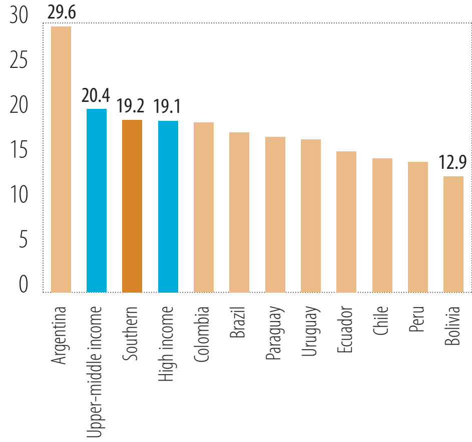
Credit growth (% change)



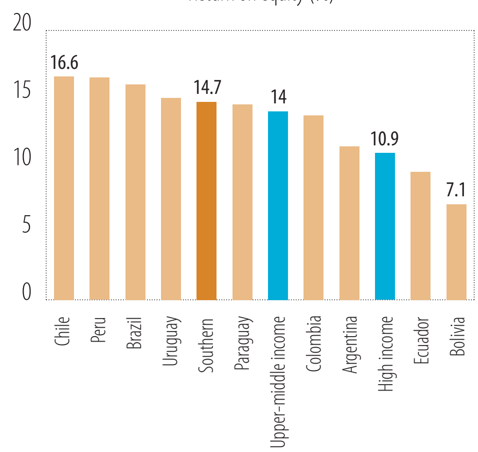
Loan to deposit ratio (%)



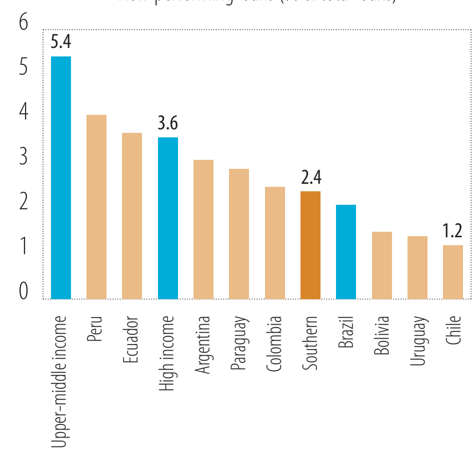
Capital adequacy ratio (%)



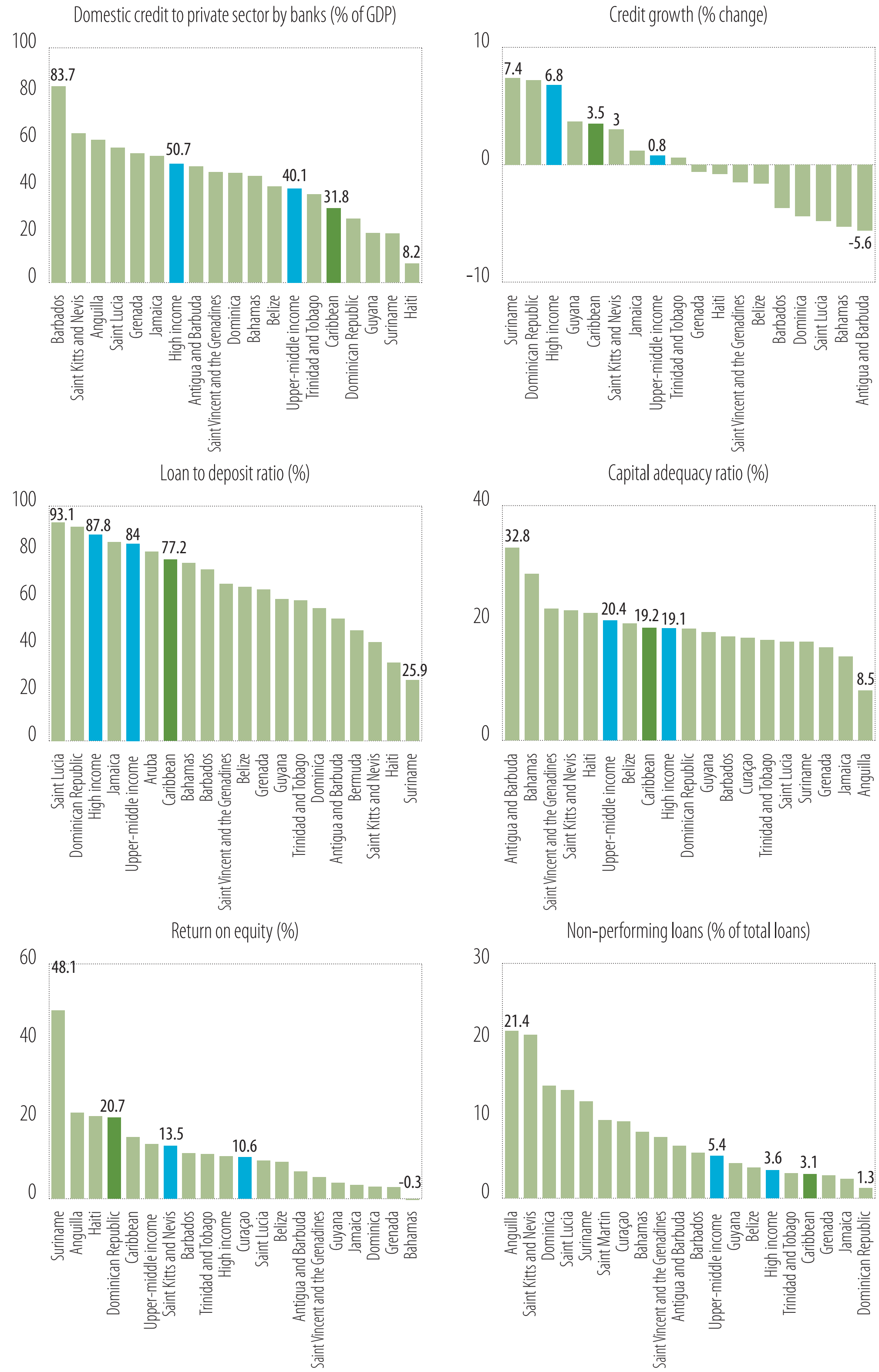
Return on equity (%)



Non-performing loans (% of total loans)



Caribbean



Domestic credit to private sector by banks (% of GDP)
100
80
60
40
20
0
83.7
50.7
40.1
31.8
8.2
Barbados
Saint Kitts and Nevis
Anguilla
Saint Lucia
Grenada
Jamaica
High income
Antigua and Barbuda
Saint Vincent and the Grenadines
Dominica
Bahamas
Belize
Upper-middle income
Trinidad and Tobago
Caribbean
Dominican Republic
Guyana
Suriname
Haiti
Credit growth (% change)
10
0
-10
7.4
6.8
3.5
3
0.8
-5.6
Suriname
Dominican Republic
High income
Guyana
Caribbean
Saint Kitts and Nevis
Jamaica
Upper-middle income
Trinidad and Tobago
Grenada
Haiti
Saint Vincent and the Grenadines
Belize
Barbados
Dominica
Saint Lucia
Bahamas
Antigua and Barbuda
Loan to deposit ratio (%)
100
80
60
40
20
0
93.1
87.8
84
77.2
25.9
Saint Lucia
Dominican Republic
High income
Jamaica
Upper-middle income
Aruba
Caribbean
Bahamas
Barbados
Saint Vincent and the Grenadines
Belize
Grenada
Guyana
Trinidad and Tobago
Dominica
Antigua and Barbuda
Bermuda
Saint Kitts and Nevis
Haiti
Suriname
Capital adequacy ratio (%)
40
20
0
32.8
20.4
19.2
19.1
8.5
Antigua and Barbuda
Bahamas
Saint Vincent and the Grenadines
Saint Kitts and Nevis
Haiti
Upper-middle income
Belize
Caribbean
High income
Dominican Republic
Guyana
Barbados
Curaçao
Trinidad and Tobago
Saint Lucia
Suriname
Grenada
Jamaica
Anguilla
Return on equity (%)
60
40
20
0
48.1
20.7
13.5
10.6
-0.3
Suriname
Anguilla
Haiti
Dominican Republic
Caribbean
Upper-middle income
Saint Kitts and Nevis
Barbados
Trinidad and Tobago
High income
Curaçao
Saint Lucia
Belize
Antigua and Barbuda
Saint Vincent and the Grenadines
Guyana
Jamaica
Dominica
Grenada
Bahamas
Non-performing loans (% of total loans)
30
20
10
0
21.4
5.4
3.6
3.1
1.3
Anguilla
Saint Kitts and Nevis
Dominica
Saint Lucia
Suriname
Saint Martin
Curaçao
Bahamas
Saint Vincent and the Grenadines
Antigua and Barbuda
Barbados
Upper-middle income
Guyana
Belize
High income
Trinidad and Tobago
Caribbean
Grenada
Jamaica
Dominican Republic

Climate risks for Latin America and the Caribbean
Are banks ready for the green transition?

European Investment Bank | Global

Economics Department
economics@eib.org
www.eib.org/economics

European Investment Bank
98-100, boulevard Konrad Adenauer
L-2950 Luxembourg
+352 4379-22000
www.eib.org – info@eib.org

pdf: ISBN 978-92-861-5571-0

2023-0142

Annex 533

"Investing in Climate, Investing in Growth", *OECD*, 23 May 2017

Investing in Climate, Investing in Growth

OECD

Investing in Climate, Investing in Growth

OECD
BETTER POLICIES FOR BETTER LIVES

Please cite this publication as:
OECD (2017), *Investing in Climate, Investing in Growth*, OECD Publishing, Paris.
http://dx.doi.org/10.1787/9789264273528-en

ISBN 978-92-64-27351-1 (print)
ISBN 978-92-64-27352-8 (PDF)

Revised version, June 2019
Details of revisions available at:
http://www.oecd.org/about/publishing/Corrigendum-Investing-in-Climate-Investing-in-Growth.pdf

Photo credits: Cover © Baseline Arts

Corrigenda to OECD publications may be found on line at: *www.oecd.org/about/publishing/corrigenda.htm*.

Foreword

Governments around the world are striving to re-ignite growth in their economies while reducing widening inequalities. At the same time, they are working hard to implement the climate goals agreed by the global community under the Paris Agreement. These challenges are not mutually exclusive. We have a unique window of opportunity to bring the climate and economic growth agendas together and to generate inclusive economic growth in the short term, while ensuring that we meet the climate challenge in the longer term.

Investing in Climate, Investing in Growth *lays out the case for governments to pursue an integrated policy approach that combines climate action with fiscal initiatives and structural reforms. It is clear from the report's analysis that countries can achieve strong and inclusive economic growth while reorienting their economies towards development pathways with low greenhouse gas emissions and high resilience to the effects of climate change. The report sees potential to increase long-run output by up to 2.8% on average across G20 countries in 2050, with a net effect of nearly 5% if mitigated climate impacts are taken into account. Importantly, growth impacts are positive in the near-term too: the report sees potential for a net GDP effect of around 1% for G20 economies by 2021.*

However, it is also increasingly clear that meeting the Paris Agreement's goals will require countries to step up ambition, enhance co-operation across borders and strengthen domestic policies and implementation on the ground as a matter of urgency. Moreover, there is a need for governments to take immediate action. The decisions that we take now on key issues such as infrastructure and the structure of our economies will be critical in ensuring a longer term future that enhances rather than diminishes well-being. Proactive, forward-looking policies to facilitate a just transition for affected businesses and households will also be vital to ensure that reform is inclusive, progressive and good for business, particularly in vulnerable regions and communities.

This report has been produced in the context of the German G20 Presidency, which has placed climate squarely on the G20 agenda in recognition of the fact that the growth and climate agendas are mutually supportive. Indeed, adopting an inclusive, low-emission and climate-resilient growth agenda is an opportunity to reorient G20 growth objectives as the group's 2014 Brisbane commitment to 2% growth nears its end in 2018.

The OECD is supporting countries, developed and developing, to create more effective policy approaches to address the growth, inclusiveness and climate challenges in a holistic way. For OECD member countries, it will not be easy to achieve the transition from carbon-intensive to low-emissions economies while seeking to re-ignite growth. For partner economies, the challenge is to avoid locking in emissions-intensive development paths while pursuing growth and development opportunities. Our report shows that there are significant benefits to an integrated approach to the climate and growth challenge.

Angel Gurría
OECD Secretary-General

Acknowledgements

This report was prepared under the supervision of Anthony Cox (OECD Environment Directorate) and Andreas Schaal (OECD Sherpa Office and Global Relations Secretariat), supported by a core team of Andrew Prag, Justine Garrett, Richard Baron, Galina Alova, Sarah Finke, Elizabeth Del Bourgo and Makeda Yohannes (OECD Environment Directorate) and Roger Dubach, Nicolas Pinaud and Nejla Saula (Sherpa Office). Gabriela Ramos (OECD Sherpa and Chief of Staff), Catherine Mann (OECD Chief Economist) and Simon Upton (OECD Environment Director) provided strategic guidance to the project.

The OECD would like to thank the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) for providing financial support to the project. A number of staff from the BMUB provided guidance and comments on the report including Norbert Gorißen, Carolin Zerger and Claudia Keller.

The report was authored by teams drawn from a number of OECD directorates: Environment Directorate (ENV); Economics Department (ECO); Directorate for Financial and Enterprise Affairs (DAF); Development Cooperation Directorate (DCD); Trade and Agriculture Directorate (TAD); Centre for Tax Policy and Administration (CTP) and the International Transport Forum (ITF). The Directorate for Public Governance also contributed. Simon Buckle (ENV) supervised the preparation of Chapters 2 and 3, Andrés Fuentes-Hutfilter and Christian Kastrop (ECO) supervised the preparation of Chapter 4, and Ana Novik (DAF) supervised the preparation of Chapters 5, 6 and 7.

The authors for the individual chapters were:

Chapter 1	Lead author was Andrew Prag with contributions from Galina Alova, Richard Baron, Anthony Cox, Roger Dubach, Justine Garrett, Andreas Schaal, Simon Upton and the other chapter authors below.
Chapter 2	Lead authors were Simon Buckle and Michael Mullan, with contributions from Jo Cadilhon, Jennifer Calder, Robert Dellink, Guillaume Gruère, Marit Hjort, Frank Jesus, Virginie Marchal, Mariana Mirabile, William Wright, Ziga Zarnic, and staff from the Met Office Hadley Centre for Climate Science and Services.
Chapter 3	Lead authors were Virginie Marchal and Mariana Mirabile, with contributions from Richard Baron, Simon Buckle, Jo Cadilhon, Jenny Calder, Naeeda Crishna Morgado, Marit Hjort, Bérénice Lasfargues, Ziga Zarnic, and staff from Grantham Institute, Imperial College London.
Chapter 4	Lead authors were Andrés Fuentes-Hutfilter and Annabelle Mourougane, with contributions from Shardul Agrawala, Jarmila Botev, Rob Dellink, Dennis Dlugosch, Jean-Marc Fournier, Olivier Durand-Lasserve, Christian Kastrop and Tomasz Kozluk.
Chapter 5	Lead authors were Andrew Prag and Enrico Botta, with contributions from Geraldine Ang, Johanna Arlinghaus, Richard Baron, Jo Cadilhon, Kurt Van Dender, Luisa Dressler, Florens Flues, Franck Jesus, Michael Mullan, Ana Novik, Jehan Sauvage, Ronald Steenblik, Cristina Tebar-Less and Nicolas Wagner.
Chapter 6	Lead author was Richard Baron with contributions from Gianpiero Mattera, Filipe Silva, Ronald Steenblik, Ziga Zarnic, staff from E3G and the Just Transition Centre, and Genevieve McInnes.
Chapter 7	Lead authors were Joel Paula, Naeeda Crishna Morgado, Raffaele della Croce and Berenice Lasfargues, with contributions from Abderrahim Assab, Wiebke Bartz, Flore-Anne Messy, Ana Novik, Haje Schutte, and Guillaume Simon.

Particular thanks are expressed to the members of the project's Advisory Council for their very helpful review and comments:

- Isher Ahluwalia (Chairperson, Board of Governors, the Indian Council for Research on International Economic Relations (ICRIER))
- Luis Alberto Moreno (President, IDB) and his team (Amal Lee-Amin)
- Kate Brandt (Lead for Sustainability, Google) and Francois Sterin (Director, Global Infrastructure, Google)
- Sharan Burrow (General Secretary, ITUC)
- Ottmar Edenhofer (Deputy Director and Chief Economist, PIK)
- Justin Lin (Director, Center for New Structural Economics; Professor and Honorary Dean National School of Development, Peking University)
- Ajay Mathur (Director General, TERI)
- Axel Ockenfels (Professor, University of Cologne)
- Ngozi Okonjo-Iweala (Former Managing Director, World Bank; Chair of the Board, Global Alliance for Vaccines and Immunization (GAVI) and African Risk Capacity (ARC))
- Paddy Padmanathan (CEO and President, ACWA Power) and David Ungar (Executive Director, ACWA Power)
- Robert N. Stavins (Albert Pratt Professor of Business & Government, Harvard Kennedy School)
- Nicholas Stern (Chair, Grantham Research Institute on Climate Change and the Environment)
- Jean-Pascal Tricoire (CEO, Schneider Electric)
- Laurence Tubiana (Former French Ambassador for Climate Change; Professor, Sciences-Po Paris; CEO of the European Climate Foundation).

The OECD would also like to thank the International Energy Agency for its helpful input and comments on the report, in particular Laura Cozzi and Timur Guel, along with Pierpaolo Cazzola, Christophe McGlade, Jacob Teter, Michael Waldron and Brent Wanner. The International Renewable Energy Agency also provided helpful comments.

In addition, the OECD thanks the project's Knowledge Partners for their contributions to and comments on the report:

- Climate Disclosure Standards Board (CDSB)
- COPPE at Universidade Federal do Rio de Janeiro (UFRJ) (Brazil)
- Development Research Center of the State Council of China (DRC, China)
- E3G
- European Development Finance Institutions Association (EDFI)
- Fiel (Argentina)
- Fondazione ENI Enrico Mattei (FEEM)
- Imperial College London
- Institute for Sustainable Development and International Relations (IDDRI) Deep and the Decarbonization Pathways Project (DDPP)
- International Development Finance Club (IDFC) Secretariat, KfW
- Just Transition Centre of the International Trade Union Confederation
- King Abdullah Petroleum Studies and Research Center (KAPSARC, Saudi Arabia)
- Met Office, Hadley Centre for Climate Science and Services (United Kingdom)
- Observer Research Foundation (ORF, India)

Thanks must also go to the following individuals for their input and comments: Amar Battacharya, Brookings Institute; Emmanuel Guérin, European Climate Foundation, Joeri Rogelj, International Institute for Applied Systems Analysis (IIASA); Ted Nace, Global Coal Tracker; Guineng Chen and Jari Kauppila, ITF; Dale Rothman, Pardee Centre; and David Blandford, Penn State College of Agriculture Science. Thanks also to the many OECD colleagues who provided helpful comments including Dorothée Allain-Dupré, Ruben Bibas, Timothy Bishop, Jonathan Brooks, Jean Chateau, Emilio Chiofalo, Jan Corfee-Morlot, Jane Ellis, Luis-Mario Hernandez, Kaori Miyamoto, Paul O'Brien, Giuseppe Nicoletti, Jens Sedemund and David Turner.

The many comments and suggestions provided by the following committees are gratefully acknowledged:

Committee for Agriculture, Committee for Scientific and Technological Policy, Committee on Financial Markets, Committee on Fiscal Affairs, Committee on Industry, Innovation and Entrepreneurship, DAC Network on Environment and Development Co-Operation, Development Assistance Committee, Employment, Labour and Social Affairs Committee, Economic Policy Committee, Environment Policy Committee, Insurance and Private Pensions Committee, Investment Committee, Joint Working Party on Agriculture and Environment, Joint Working Party on Trade and Environment, Joint Meeting of Tax and Environment Experts, Senior Officials from Centres of Government, Trade Committee, Working Party No. 1 on Macro-Economic and Structural Policy Analysis, Working Party on Climate, Investment and Development, Working Party on Integrating Environmental and Economic Policies.

The OECD is also grateful to the participants of the different workshops:

- OECD Workshop on "*Financing green infrastructure*", Paris, 3 November 2016
- OECD Roundtable on "*Scaling up climate investment through National Development Banks (NDBs), Multilateral Development Banks (MDBs), and Development Finance Institutions (DFIs)*", Casablanca, Morocco, 5 November 2016
- OECD Workshop on "*Make the economic case for the Paris Agreement: Modelling the macroeconomic consequences of climate change action*", Paris, 24-25 November 2017
- OECD Workshop on "*Low-emission and climate-resilient development pathways*", Paris, 11 January 2017
- Roundtable discussion on "*The role of national development banks, multilateral development banks and bilateral development finance institutions in scaling up investment in low-carbon and climate-resilient infrastructure*", Paris, 22 February 2017
- Workshop co-organised by ORF and the OECD on "*Growth, Investment and the Low-Carbon Transition in India*", Delhi, 7 March 2017
- Workshop co-organised by DRC and the OECD on "*Investment and the Low-carbon transition in China and the world*", Beijing, 12 April 2017

The report was prepared for publication under the direction of Elizabeth Del Bourgo from the OECD Environment Directorate, with editorial work being undertaken by Andrew Johnston (Words for Change), layout by Pierre-Yves Perez-Queyroi (Pykha) and cover design by Andrew Esson (Baseline Arts Ltd). Thank you to OECD Public Affairs and Communications Directorate colleagues Janine Treves for editorial and content support, and Catherine Bremer for media relations support. Production support was provided by Stéphanie Simonin-Edwards of the OECD Environment Directorate.

Table of contents

Tables

Figures

Executive summary

Achieving a growth path that is resilient, inclusive and sustainable is one of the top policy priorities of our time. Governments around the world are facing the triple imperatives of re-invigorating growth while improving livelihoods and urgently tackling climate change, in line with the goals of the Paris Agreement. This report argues that boosting economic growth, improving productivity and reducing inequalities need not come at the expense of locking the world into a high-emissions future. It is the *quality* of growth that matters.

With the right policies and incentives in place – notably strong fiscal and structural reform combined with coherent climate policy – governments can generate growth that will significantly reduce the risks of climate change, while also providing near-term economic, employment and health benefits. Such a climate-compatible policy package can increase long-run GDP by up to 2.8% on average across the G20 in 2050 relative to a continuation of current policies. If the positive impacts of avoiding climate damage are also taken into account, the net effect on GDP in 2050 rises to nearly 5% across developed and emerging economies of the G20.

Investment in modern, smart and clean infrastructure in the next decade is a critical factor for sustainable economic growth, especially as infrastructure generally has suffered from chronic underinvestment since before the financial crisis. The report estimates that USD 6.3 trillion of investment in infrastructure is required annually on average between 2016 and 2030 to meet development needs globally. An additional USD 0.6 trillion a year over the same period will make these investments climate compatible, a relatively small increase considering the short and long-term gains in terms of growth, productivity and well-being. The additional investment cost is likely to be offset over time by fuel savings resulting from low-emission technologies and infrastructure.

Furthermore, the current fiscal environment provides a window of opportunity to take action now. Low interest rates have increased fiscal space in many countries and, where there is less fiscal space, opportunities exist to optimise the tax and spending mix to align stronger economic growth with inclusive, low-emission, resilient development. Well-aligned climate, fiscal and investment policies will further maximise the impact of public spending to leverage private investment.

Finance will be a key factor: capital must be mobilised from both public and private sources, supported by a variety of financial instruments tuned for low-emission, climate-resilient infrastructure. Public financial institutions need to be geared for the transition, while the financial system itself should take greater steps to correctly value and incorporate climate-related risks. Development banks and finance institutions – multilateral, bilateral and national – all have a critical role to play here too, not only using their balance sheets to amplify available resources, but also developing green finance in partner countries, including through policy and capacity building support.

Getting the fundamental climate policies right is essential to aligning incentives. There is a need to accelerate the reform of inefficient fossil-fuel subsidies and broaden the carbon pricing base, focusing on tracking the impact and sharing policy experiences. Making greater use of public procurement to invest in low-emission infrastructure can trigger industrial and business model innovation through the creation of lead markets.

At the same time, we must recognise that sustainable growth also means inclusive growth. Coherent climate and investment policies, effective fiscal and structural policy settings and reforms must work together to facilitate the transition of exposed businesses and households, particularly in vulnerable regions and communities. Early planning for the transition is essential if societies are to avoid stranded assets in fossil-fuel-intensive industries and stranded communities alongside them.

Looking beyond energy production and use, developments in agriculture, forestry and other land-use sectors will enable scaling up the pace of the transformation needed elsewhere in the economy. Current stocks of carbon in tropical forests and other ecosystems need to be protected and their ability to act as carbon sinks enhanced wherever possible. Research and development needs to be significantly strengthened and followed by rapid demonstration and diffusion of technological breakthroughs that will reduce and eliminate greenhouse gas emissions from energy, industry and transport, and improve agricultural yields and crop resilience. In addition, the feasibility to deploy "negative emissions" at scale remains a major uncertainty, despite being an important feature of most scenarios consistent with the Paris Agreement's goals.

Finally, international co-operation remains fundamental to managing climate risks. Countries' current contributions to emissions reduction beyond 2020 are not consistent with the Paris temperature goal, and need to be scaled up rapidly. Support for action in developing countries will be important, not just for mitigation but also to improve the resilience and adaptive capacity of countries facing the greatest climate challenges. Climate impacts will grow, even if we achieve the Paris temperature goal. We need flexible and forward-looking decision-making to increase resilience in the face of these risks. Managing the interdependences between climate, food security and biodiversity goals will be critical to achieving the Sustainable Development Goals and long-term robust growth.

Chapter 1

A decisive transition for growth and climate

Governments around the world are facing the triple imperatives of re-invigorating growth while improving livelihoods and urgently tackling climate change. This chapter contains an extended synthesis of the report, showing how acting on climate change can also be good for growth, provided the right policies and structural reforms are put in place. After setting the scene for combined action on climate and growth, the synthesis presents results on the macro-economic implications of a "decisive transition" to a low-emission, high-growth and resilient future. The synthesis then lays out development pathways compatible with the Paris Agreement and how they vary across country types, as well as the need to scale and shift infrastructure investment. Turning to policy, the synthesis also presents the mix of structural and targeted climate policies required, the implications of the transition for exposed businesses and workers and how governments can address them, and changes needed to the financial system. It concludes with the main policy messages arising from the report.

Creating the conditions for sustainable growth

The global economy is not generating the level or quality of growth to which the citizens of G20 countries aspire. Productivity growth, the key factor that increases income per capita, has been declining for years in many countries. Widening inequalities, often related to the slowdown in productivity growth, are forcing a rethink about how the benefits of growth are shared. Many advanced countries face concerns about persistent unemployment and how to meet expectations about pensions, health and education. For some economies, this is exacerbated by ageing societies. Developing and some emerging economies have the benefit of a more dynamic demography, though many have concerns about the quality of investment and regulation. In their 2016 communiqué, G20 leaders recognised that "the use of all policy tools – monetary, fiscal and structural – individually and collectively" is needed both to support aggregate demand in the short term and to build the foundations for resilient, longer-term growth prospects.

The top priority for many G20 countries is to reinvigorate their economies, but the quality of that growth is vital. To improve lives and well-being in the short-term, growth needs to be inclusive, with benefits felt by the whole population. Economic growth over the last two centuries has led to staggering increases in wealth and well-being for much – but not all – of the world's population. To continue to improve well-being over a longer time horizon, the sources of growth need to be sustainable economically, socially and environmentally. To date, growth has exploited natural capital to meet the demands of rising populations, using technology largely based on abundant fossil fuels. Those fuels have been cheap because little account has been taken of their social and environmental costs.

Climate change: a systemic risk for growth

The impact of the current growth model on the natural environment now threatens the foundations of continued growth. While local pollution is increasingly driving momentum for reform, environmental pressures, including climate change, are no longer just local or regional; they pose profound challenges to global development. The scale of potential damage from climate change poses a major systemic risk to our future well-being and the ecosystems on which we depend, in particular for societies in less-developed, less-resilient countries. The pace and scale of the required economic transformation is unprecedented, if the worst of these risks are to be avoided; planning and investment in adaptation and resilience are also essential to reduce vulnerability to climate change.

Governments acknowledged the intrinsic importance of climate change for sustainable development and poverty alleviation in both the Paris Agreement and the 2030 Agenda for Sustainable Development. In Paris, countries collectively agreed to strengthen the global response to climate change including by limiting the global average surface temperature increase to well below 2°C and to pursue efforts to limit it to 1.5°C above pre-industrial levels, while increasing the ability to adapt to adverse impacts of climate change.

Most countries have proposed national action plans under the Paris Agreement, but collectively these are insufficient to achieve the long-term objective of the agreement. The Nationally Determined Contributions to 2030 are a positive step, but even if they were fully implemented, warming would reach around 3°C, leading to severe disruption and economic damage. Reasons for insufficient ambition vary, but commonly include perceived high economic and social costs of climate policies, and concerns about competitive disadvantage if stringent climate policies are not mirrored elsewhere. These concerns persist despite the "enhanced transparency framework" of the Paris Agreement. In addition, political and investment horizons have pitted the long-term benefits of low-emission development against the short-term (but ultimately unsustainable) benefits of cheaper high-carbon options. The threat of future damage from climate change has been too distant to drive sufficient early action, and short-term gain has tended to come first. But the threat of climatic disruption is not a conventional risk management issue, either temporally or spatially. While short-term costs are often local, a failure to address them will put future local and global benefits beyond reach.

Inclusive and climate-compatible growth

This report shows how action on climate change can generate inclusive economic growth in the short term, in addition to securing longer-term growth and well-being for all citizens. Governments can not only build strong growth but also avoid future economic damage from climate change if they collectively act for a "decisive transition" towards low-carbon economies. This requires combining climate-consistent, growth-enhancing policies with well-aligned policy packages for mobilising investment in low-emission infrastructure and technologies.

Investment in modern infrastructure is an important basis for economic growth, but underinvestment has been prevalent since the financial crisis. Energy, water supply, sanitation and waste management, mobility services and communications are foundations for economic activity and also essential for achieving the Sustainable Development Goals. Many advanced economies have suffered from a deficit of public infrastructure investment, hurting growth. Most emerging economies need massive investment to provide a growing population with universal access to modern services.

Countries are now facing a fundamental choice: the type of infrastructure investments they make will either support or seriously undermine future global well-being. As well as being a source of growth, infrastructure investment is a key determinant of future GHG emissions and resource efficiency, both directly (for example, through the type of power plants installed) and indirectly, by influencing behaviours (for example, through transport systems and urban planning). The window for making the right choices is uncomfortably narrow. The lifespans of much infrastructure and related physical investment means that future GHG emissions are going to be locked in by investment choices in the next decade, as infrastructure needs expand with the world economy. While investing in new and improved infrastructure is an important part of getting growth going now, investing in the right kind of infrastructure will deliver growth that can last. To manage climate risks and deliver long-term sustainable growth, infrastructure investment needs to be low-emission, energy-efficient and climate-resilient.

A unique opportunity

Current economic conditions – including low real interest rates in most countries – afford many governments the opportunity to invest in the right infrastructure now, to reignite growth while also paving the way to achieving the Paris Agreement goals. Governments need to bring together structural policy reforms, effective climate policies and the progressive alignment of regulatory frameworks to ensure effective action. A combined agenda for climate and growth offers numerous economic opportunities, including enhanced markets for low-emission infrastructure, technologies and services; increased market confidence spurred by greater climate policy clarity; and enhanced incentives for innovation and efficiency. These and other opportunities are relevant as the G20 prepares to revisit its Brisbane "2% upside growth" commitment and strengthen performance on growth; up to now, G20 countries have reached less than half of the 2% goal. The timing and mix of the policy interventions required will very much depend on countries' different developmental imperatives and exposure to climate risks.

The transition will not succeed unless the low-carbon economy is inclusive. To make pro-climate growth policies politically feasible, their implications for both households and businesses need to be taken into account. Beyond a well-functioning tax and welfare system, targeted measures can compensate for any potentially regressive impacts of climate policy on poor households. Past experience of industrial transitions shows that workers and communities relying on GHG-intensive activities should be actively engaged early in planning the transition. Where restructuring or plant closures are likely, authorities should aim for transparency and work with relevant companies, sectors and communities to develop economically sustainable alternatives and gain political and social support for policy measures. Clear policy signals are also essential to guide the transformation of technologies and business models for a low-GHG economy.

Acting together for better growth

The benefits of combined action on growth and climate increase as more countries act in a concerted way. Simultaneous action by countries generates economies of scale in climate solutions, magnifies the gains from learning and hastens a decline in technology costs, increasing the penetration of new technologies. Simultaneous action can also reduce the concerns of firms that competitors in countries not facing carbon pricing or regulation would be at an advantage.

Recognising their different economic structures and level of development, members of the G20 are well positioned to take the lead in uniting climate and growth efforts. The G20 countries not only account for 85% of global GDP and 80% of CO_2 emissions, they have far-reaching influence on the rest of the world through innovation, trade and development finance. They are also, collectively, leading the transition: G20 countries are home to 98% of global installed capacity of wind power, 97% of solar photovoltaic (PV) power and 93% of electric vehicles (IEA, 2017). While efforts to reduce emissions and sequence policies will vary from country to country, the G20 could spearhead the transition to low-carbon growth, generating technology cost reductions and best practices that will further accelerate the transition globally. Solar PV costs have declined about 80% in leading markets since 2010, for example. If G20 countries do not take the lead, it is hard to see how the transition can be effected.

A "decisive transition" for climate and growth

The current global macroeconomic environment – including low interest rates – provides an opportunity to take swift action to address climate change while boosting economic growth. Spurring investment in smart, modern, clean and resilient infrastructure, if combined with stronger fiscal and structural policies in a synergistic way, can boost growth in the short term and underwrite robust long-term growth, in both advanced and emerging economies. Low interest rates have increased fiscal space, giving governments more flexibility over spending choices without compromising their future financial position. Even in countries where there is less fiscal space, there are opportunities to optimise the tax and spending mix to align stronger economic growth with inclusive and low-carbon development.

Many policies aimed at strengthening growth can also support the transition to low-emission pathways; by the same token, measures aimed at stimulating investment in low-emission infrastructure can be good for growth. Economic growth and the low-carbon transition both depend on the development and diffusion of new technologies and efficient reallocation of resources towards both low-carbon and high-productivity economic activity. Policies that stimulate technological diffusion and facilitate resource reallocation thus work for both objectives and can ensure a cost-effective low-carbon transition. Such measures can be disruptive, but effects can be offset by spreading the benefits of growth widely, and through policies that improve access to new economic opportunities (education, vocational training) and provide an adequate social safety net to workers.

A decisive transition to spur growth while limiting climate change

New OECD modelling work presented in this report builds on IEA (2017) to show how combining economic reforms with ambitious climate policies in an integrated, synergistic manner can spur economic growth while also mobilising the investment needed to achieve longer-term climate objectives. Results suggest that such a collective "decisive transition" can boost long-run output by 2.8% on average across the G20, when comparing a current policies trajectory to a pathway set to hold warming below 2°C with a probability of 50% (Figure 1.1, right-hand panel). Importantly, the net effect on growth is also positive in the short term (left-hand panel).

The modelled growth effect is driven by a combination of investment in low-emission, climate-resilient infrastructure; an additional fiscal initiative to fund climate-consistent non-energy infrastructure; pro-growth reform policies to improve resource allocation; technology deployment; and green innovation. The benefits of combined growth and climate policies more than offset the impact of higher energy prices, tighter regulatory settings, and high-carbon assets that may become economically stranded before the end of their economic life. Carbon-tax revenues are assumed to be used to lower public debt in most countries. The overall macroeconomic benefits of the modelled policy package therefore also include substantial reductions in most countries' public debt-to-GDP ratios.

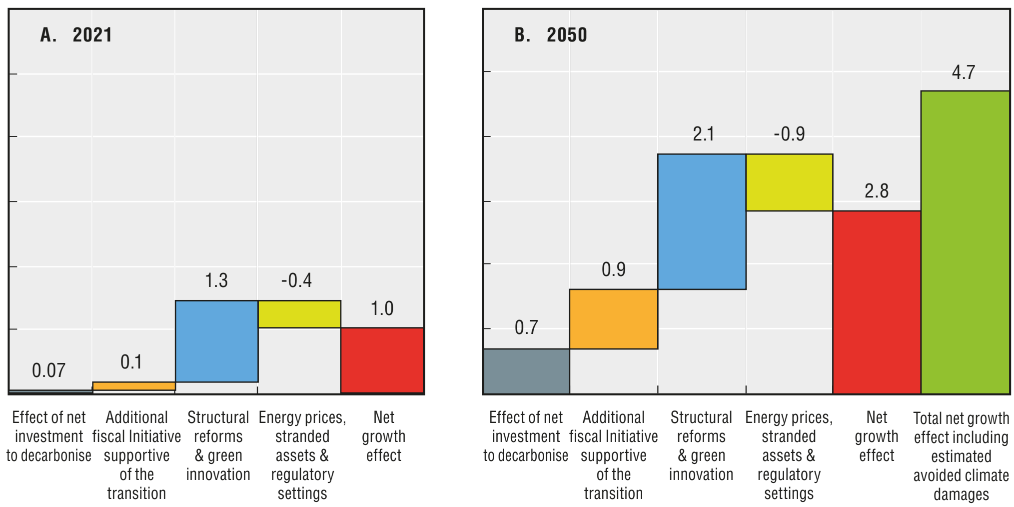
Avoided climate damages bring additional economic gains

If estimates for the positive impacts of avoiding damage from climate change are also accounted for, the net effect for 2050 rises to 4.7% higher than it would be if governments take no further action. While some economic damages are already captured in the modelling baseline, damages from climate change could pose a much greater threat to economic growth and well-being through mechanisms difficult to capture in economic modelling. The impact of these severe non-linear and unpredictable economic damages, such as flooding of coastal regions and increased frequency and strength of extreme weather events, could be very significant. Complementing model results with fuller damage estimates is important to give a more realistic picture of the long-term benefits of climate-friendly growth now. In addition, in the absence of action to reduce emissions, significant further damage can be expected between 2050 and 2100, outside of the timeframe of this exercise. Upper estimates of GDP costs without climate action range between 10 and 12% annually on a global scale by 2100.

The implications of a decisive transition will vary depending on a country's economic structure, but even fossil fuel exporters can offset losses and boost economic growth if policies are well chosen. This is a significant finding as climate action is usually expected to impose costs on fossil fuel exporters, including lower output and less employment in fossil fuel export activities. However, in a decisive transition these costs can be mitigated if carbon-tax revenues are judiciously recycled, in parallel with well-managed pro-growth reforms and proactive fiscal policies. The resulting positive effect on growth can more than outweigh the impact of stranded assets and higher energy prices. Results suggest the GDP boost would vary from 2% to 3% by 2050 in different G20 economies, not including avoided damages.

Figure 1.1. **Positive growth effects for the G20 by combining climate action with economic reforms in a decisive transition (50% probability of achieving 2°C)**

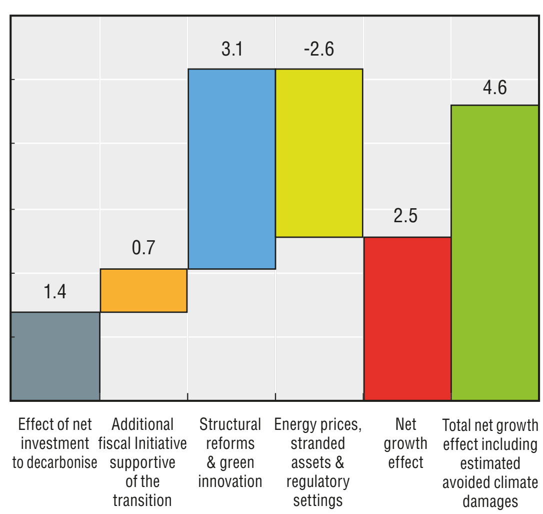
Average across G20, GDP difference to baseline, %



Note: See note under Figure 1.2.

Figure 1.2. **Positive growth effects in 2050 for the G20 by combining climate action with economic reforms in a more ambitious scenario (66% probability of achieving 2°C)**

Average across G20, GDP difference to baseline, %



Note: The average G20 is a weighted average of selected G20 economies, which represents 88% of the G20 countries (excluding the European Union). "Net investment to decarbonise" comprises the effects of specific investment needed to achieve a 2°C climate objective. "Fiscal initiative" includes additional investment in climate-friendly non-energy infrastructure and soft infrastructure (e.g. education and research). Total investment corresponds to an increase in public investment in all countries of 0.5% of GDP. Countries that experienced disinvestment as a result of mitigation policies are assumed to compensate for this disinvestment. The structural reform modelled here includes a package of measures to improve economic flexibility and resource allocation, calculated using the OECD Product Market Regulation index. Innovation captures the increase in R&D spending necessary to reach a 2°C scenario (50% scenario) and equivalent to 0.1% GDP (66% scenario). Stranded assets are consistent with IEA estimates. Regulatory setting captures the reduced costs of the transition in a more flexible regulatory environment. For damages, simulations presented here include only a subset of potential damages, excluding for instance damages from extreme climate events, due to difficulties in projecting their frequency, severity and location. The exercise models global damages associated with temperature increases, using the Nordhaus (2016) damage function.

Pursuing a more ambitious climate scenario

Limiting warming to 2°C is not enough to satisfy the objectives of the Paris Agreement. While it is difficult to precisely define what "well below 2°C" and "efforts to limit to 1.5°C" mean, a step towards a more ambitious scenario can be described in which more stringent action raises the probability of holding warming below 2°C from 50% to 66%. Such a scenario is set out in a parallel report to the German G20 Presidency which this analysis draws upon (IEA, 2017). New OECD simulations suggest that this more stringent mitigation scenario can also be a strong basis for economic growth, with a GDP increase of around 2.5% for the G20 on average in 2050, further increased to about 4.6% if avoided climate damages are accounted for. Ambitious pro-growth reforms coupled with innovation, and in some countries the recycling of carbon-tax revenues, can outweigh losses resulting from potential energy price increases and stranded assets (Figure 1.2). However, this result requires caution. The macroeconomic effects of this scenario are hard to model because the speed and depth of the necessary economic changes are profound and difficult to anticipate. These changes include the stranding of some fossil-fuel-intensive energy activities, massive investments in the global stock of buildings and radical changes to transport systems. The extent of important developments cannot yet be known, such as a more resource-efficient circular economy, new business models and technological breakthroughs that could change the economics of the transition.

Costs of delaying action

There are also significant costs involved in delaying action to reduce emissions. Countries may be tempted to delay decarbonisation for several reasons, including the long-term nature of the climate threat and political resistance based on perceived short-term risk of economic, distributional or competitiveness impacts of climate policies. Such a delay would simply increase the transition costs and require a more abrupt adjustment when action does finally start. If more stringent policies were introduced later they would affect a larger stock of high-carbon infrastructure built in the intervening years, leading to higher levels of stranded assets across the economy. In a delayed action scenario where action on climate change accelerates only after 2025, GDP losses are estimated to be 2% on average across the G20 after 10 years, relative to the decisive transition, and would be higher for net fossil fuel exporting countries. The losses could materialise as soon as the delayed transition starts and could be aggravated by financial market instability. The main uncertainty concerns how many assets might be stranded. Further research is warranted on how those assets should be measured.

Decisive action by leading countries

Even if action is not fully co-ordinated internationally, pro-active countries could still see benefits of combining climate and growth policies through a leadership alliance, demonstrating the benefits to other countries over time. The competitive advantage for such leadership economies is not likely to suffer in aggregate, due to the growth benefits of action described above and because their policies would drive demand for low-GHG products and spur innovation. They would also gain from short-term co-benefits of action, such as improved human health due to lower pollution. However, the pro-active countries may need to plan for significant structural changes in the economy, especially if some firms in carbon-intensive sectors relocate to countries with less stringent policies. This reinforces the case for accompanying structural reforms, as well as measures to ensure a proper transition of the work force. Cost-efficient decarbonisation policies, including carbon pricing with astute use of revenues, are even more important in this scenario. While countries outside of the leading group could gain some short-term competitive advantage in carbon-intensive industries, they would likely face higher stranded assets later. And the burden these countries impose on other countries, including higher climate risks, will become increasingly clear and may have broader implications for a range of international geopolitical issues.

Regardless of the international picture, the appropriate combination of pro-growth policies and action on climate change will vary from country to country, depending on governance, economic and social structures. The following sections show how country characteristics will shape emissions pathways and infrastructure choices, before exploring how different combinations of structural reform and climate policies can trigger growth in various country contexts.

Pathways and priorities for a decisive transition

The long-term temperature goals of the Paris Agreement can be translated into a fixed quantity of long-lived GHGs to be released to the global atmosphere over time. This global "carbon budget" is best presented as a range, reflecting uncertainties on how the temperature target is interpreted, how the climate responds to GHG concentrations (climate sensitivity), and the role of non-CO_2 GHG emissions. The level of gross GHG emissions consistent with a given (net) carbon budget will also depend on assumptions about technologies for "negative emissions", which would allow for a temporary overshoot before emissions are removed from the atmosphere to maintain net emissions within the overall budget. The global carbon budget compatible with a 66% likelihood of remaining below 2°C is estimated to be 590-1 240 $GtCO_2$ from 2015 to the time of peak warming – roughly 15 to 30 years of fossil fuel-related CO_2 emissions at current rates.[1]

To remain within the carbon budget compatible with the Paris goals, the global emissions pathway created by a decisive transition requires three main features:

- an early peak in global emissions, as soon as possible;
- a subsequent rapid fall in GHG emissions;
- net GHG emissions near zero or net negative in the second half of the century.

The later the peak in global emissions, the greater the rate of emissions reduction required subsequently to stay within the carbon budget. Options for achieving ambitious mitigation goals may be lost if emissions peak too high or too late, and delayed action would lead to higher costs as described above. Further, failure to reach a global emissions peak before 2030 may make it impossible to limit global average surface temperature increase to well below 2°C, let alone 1.5°C. This is particularly important because although total global CO_2 emissions from energy have been flat for the past three years, the CO_2 intensity of primary energy across the G20 remains high. As growth picks up, global CO_2 emissions could therefore start to increase again unless governments take further action.

Low-emission pathways

The mitigation objective in the Paris Agreement is extremely stringent. A deep transformation of the energy sector is needed to decarbonise electricity supply, improve energy efficiency, deploy smart grids and storage to better manage electricity demand and supply, and electrify other energy end-uses such as transport and buildings. However, the energy sector is only part of the low-carbon transition story. Agriculture, forestry and other land use contribute around a quarter of total GHG emissions, around half of which is from agriculture. The land sectors act as both sources of GHGs (including methane from cattle and rice, nitrous oxide from fertiliser use) and sinks of CO_2 (from forestry and carbon stocks in soils), so they have an important influence over the carbon budget remaining for energy-related emissions.

Most scenario modelling of global pathways that keep warming "well below 2°C" require not only reducing emissions of all GHGs but also "net negative" emissions later this century.[2] Land-use and forestry will have to go from being a net emitter to a net sink of GHG emissions, including through reforestation, avoided deforestation, and conservation and recovery of soils as carbon stocks. Agriculture also has the potential to become more GHG-efficient while meeting increased food demand from rising populations, though this is dependent on demographics and dietary preferences, as well as technological progress in crop yields. Energy-related CO_2 emissions can also be reduced by using bioenergy, either for advanced biofuels or in power plants fitted with carbon capture and storage (CCS). Potentially a means to create "negative emissions", the required technologies are still not yet proven at commercial scale across relevant applications. Concerns remain over competition for land and whether enough biomass can be produced sustainably, while meeting food demand, maintaining carbon stocks and protecting biodiversity.

Adaptation pathways are important planning tools

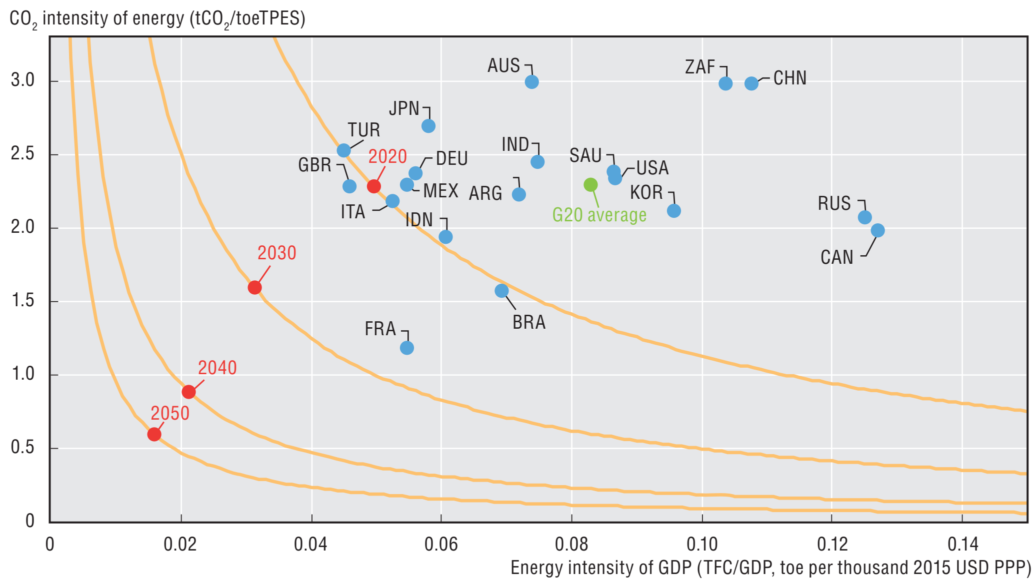
Adaptation is also at the heart of the Paris Agreement. Strong action to reduce emissions will lower the need for adaptation by reducing the intensity of climate-change impacts. Nevertheless, significant climate impacts are already locked in, so planning for and investing in adaptation and resilience is critical. Vulnerability to climate change varies greatly across sectors and within countries, shaped by geography, income, governance and development choices. Socio-economic trends and trans-boundary impacts are also relevant.

Decisions being made today will affect future vulnerability to climate change, intentionally or not. However, climate vulnerabilities are diverse and projections of local and regional change are uncertain, so it is neither possible nor desirable to address the need for adaptation comprehensively at one point in time. "Adaptation pathways" can be developed to shape near-term planning and policy decisions that reduce short-term and long-term risks. These pathways provide a means to identify path dependencies and critical decision points, creating a flexible, forward-looking approach to decision-making. National adaptation plans can strengthen the capacity of national and local decision makers to account for climate change and direct investments in resilience. Relevant tools for adaptation strategies include national risk assessment, indicator sets and in-depth evaluations of large infrastructure projects.

Pathways for different countries

Both low-emission and adaptation pathways are specific to individual countries. This is highlighted by the diversity of current CO_2 intensity of energy and energy intensity of GDP, both key determinants of CO_2 emissions. The lines in Figure 1.3 show different combinations of these two determinants resulting in the level of CO_2 emissions per unit of GDP required to be on course for the IEA 66% 2°C scenario, which this report builds on, in 2030, 2040 and 2050. The 2014 positions of G20 countries are also plotted, highlighting the different starting points and challenges facing different countries as they choose the most appropriate pathways towards the Paris objectives.

Figure 1.3. **The carbon and energy intensity of G20 economies in 2014 and the path to 2050**



Notes: The average levels for G20 countries (excluding the European Union) refer to 2014 statistical data and the IEA 66% 2°C scenario projections for 2020, 2030, 2040 and 2050. The iso lines show other feasible combinations of CO_2 intensity and energy intensity levels. Calculations assume a constant ratio for total primary energy supply (TPES) to total final consumption (TFC). Toe = tonnes of oil equivalent.

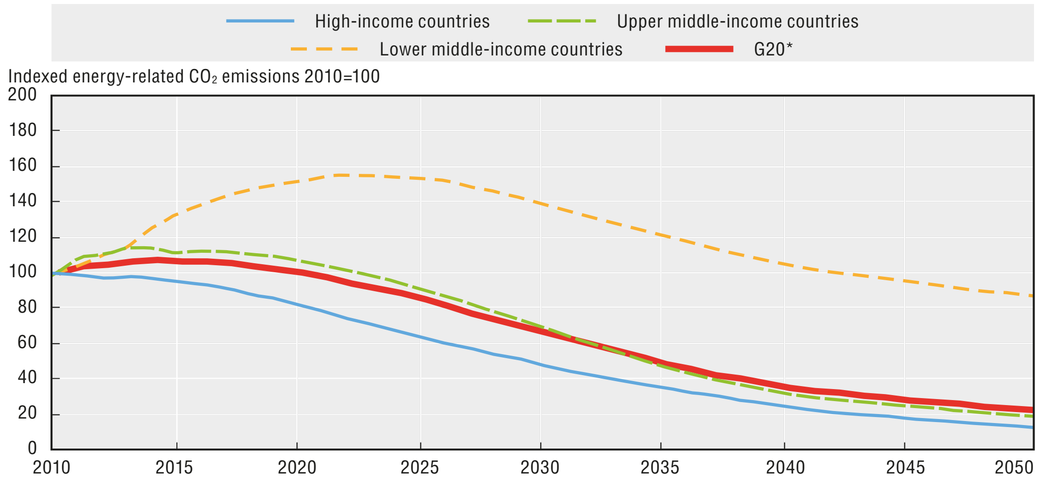
Source: Calculations based on the IEA World Indicators and IEA 66% 2°C scenario projections.

StatLink http://dx.doi.org/10.1787/888933483964

Pathways will vary according to different country circumstances. Figure 1.4 presents a new characterisation of CO_2 emissions pathways out to 2050 under the IEA 66% 2°C scenario, showing the G20 average and also groups of advanced and emerging economies. Measured against a starting point of 2010 emissions, global CO_2 emissions fall by about 80% by 2050. Advanced economies begin rapid emissions reductions from the outset and are projected to converge at very low levels by 2050. However, pathways for emerging economies are very different. Upper middle-income countries, taken together, show a gradual decline starting from the current period, also accelerating to reach low levels by 2050. Lower middle-income countries, given their stages of economic and demographic development, show continued increases in emissions to about 2025, followed by a gradual decline back to around 2010 levels.

As well as the diversity of potential country pathways, these scenarios illustrate the importance of policies (including climate support) that can combine growth with emissions reductions, to bring forward the required peak in emissions while not harming prosperity, in particular for emerging (middle-income) market economies. Understanding the appropriateness of different policies requires understanding how low-emission pathways apply to different countries, for both energy and non-energy sectors, taking into account the relative importance of energy, industry, land-use and other sources of GHG emissions. Groups of countries that share common characteristics could gain a significant advantage from joint analysis of policy developments as they develop their plans for combined growth and climate action.

Figure 1.4. **Emissions pathways by income group**

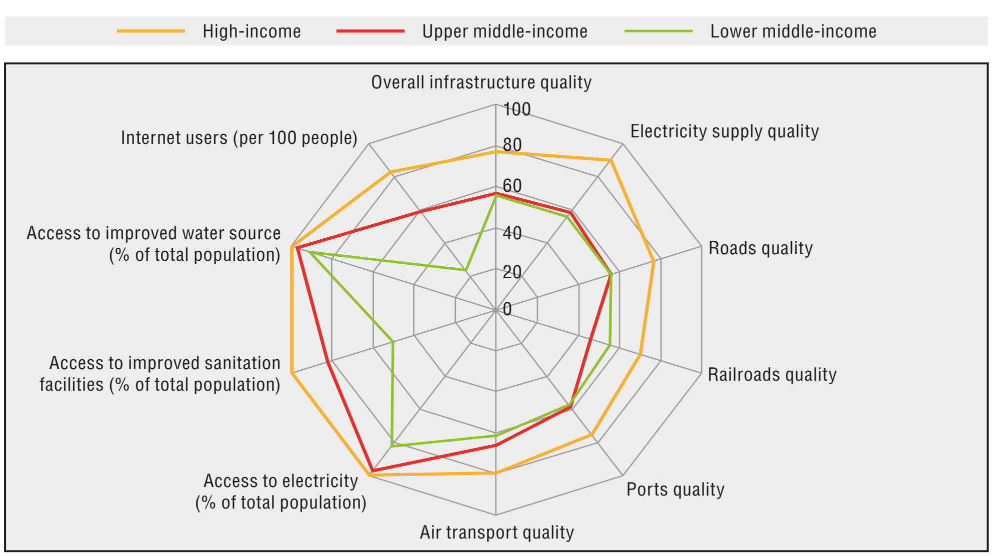


Note: Due to data limitations, G20 countries not included are Argentina, Saudi Arabia, South Africa and Turkey.
Source: IEA (2017) and OECD calculations.
StatLink http://dx.doi.org/10.1787/888933483972

Scaled-up investment in clean, resilient infrastructure

Infrastructure investment is vital to underpin economic growth as part of a decisive transition towards low-emission, climate-resilient pathways, but current levels and types of investment are inadequate. The quality of infrastructure is declining in many advanced economies, public capital stock is shrinking in some countries, and more infrastructure investment is needed in developing countries to achieve universal access to energy and basic public services. The quality of different infrastructure types, and resulting access to basic services, varies greatly across different country income groups, with implications for the quality of growth and development (Figure 1.5). For example, having nearly universal access to electricity (bottom left) does not mean that the electricity supply is of good quality (top right).

Figure 1.5. **Quality of infrastructure status and access to basic services in G20 countries, by income groups**



Sources: Authors, based on WEF (2015) and World Bank (n.d.) (accessed February 2017).
StatLink http://dx.doi.org/10.1787/888933483980

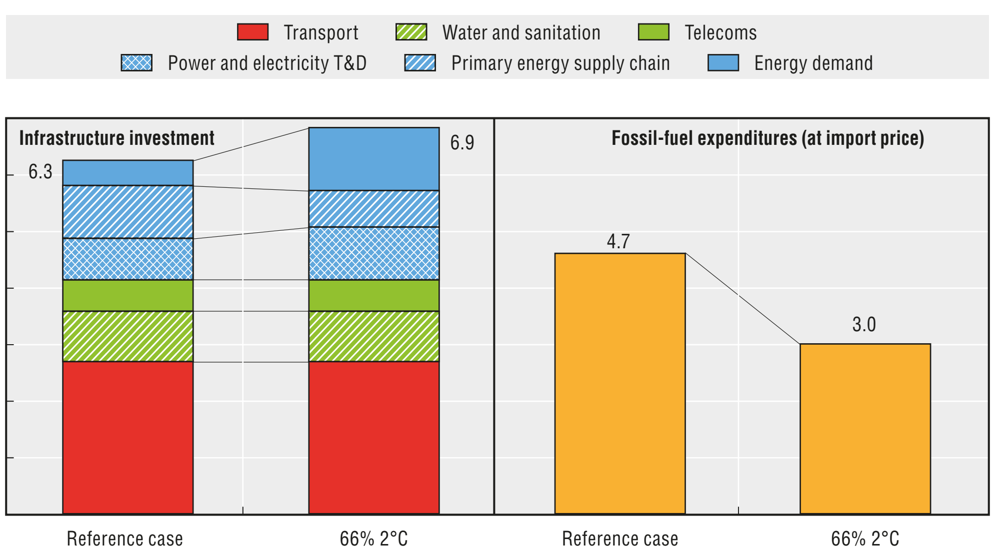
Unprecedented levels of infrastructure investment will be required to sustain growth and meet the basic needs generated by rapid population growth and urbanisation in developing countries, even before considering climate and pollution challenges. The OECD estimates that around USD 95 trillion of investments are needed from 2016 to 2030 in infrastructure (energy, transport, water and telecoms), equalling around USD 6.3 trillion per year without taking into account climate concerns. Transport represents 43% and energy 34% of those investment needs, 60% to 70% of which will be required by emerging economies.

The new estimates also suggest that for infrastructure to be consistent with the 2°C 66% scenario, investment needs reach USD 6.9 trillion per year in the next 15 years, an increase of about 10% in total infrastructure investment from the reference estimate above (Figure 1.6, left-hand panel). This covers transport, water and sanitation as well as energy supply and use. The additional capital cost is low overall and could be offset over time by fuel savings reaching USD 1.7 trillion per year up to 2030 (Figure 1.6, right-hand panel) – further reinforcing the case for robust low-emission economic growth.

Focusing on energy infrastructure, low-emission pathways require a deep transformation in the way energy is used and produced, requiring 29% more investment in the energy sector (Figure 1.6, top three segments). In the IEA 2°C 66% scenario, 95% of the electricity would need to be low-carbon by 2050, 70% of new cars would be electric, the entire existing building stock would have been retrofitted, and the CO_2 intensity of the industrial sector would be 80% lower than today (IEA, 2017). Achieving this would entail a major shift of energy supply investment towards low-carbon alternatives, and a significant increase in demand-side investments to make the economy more energy-efficient in the next few years.

Figure 1.6. **Annual infrastructure investment needs and fuel savings in a low-carbon future**

Global estimates (annual average for 2016-30, USD 2015 trillion)



Notes: Reference case assumes no further action by governments to mitigate climate change.

Sources: IEA (2017) for energy supply and demand; IEA (2016a) for road and rail infrastructure; OECD (2012) for airports and ports; McKinsey (Woetzel et al., 2016) for telecoms. The water and sanitation estimate is an average of estimates from: Booz Allen Hamilton (2007), McKinsey (Woetzel et al., 2016) and OECD (2006).

StatLink http://dx.doi.org/10.1787/888933483994

While it is clear that a boost in investment is needed in the short term to engage on a low-emission pathway, the exact amount remains uncertain. Other modelling exercises (IEA 2016) show that in the long term (to 2050), overall investment needs could actually be lower in a low-carbon scenario than in a business-as-usual scenario. This would include savings from modal shifts to low-carbon transport, particularly at the urban level, where fewer vehicles and less parking space would be needed. In the long term, a world less reliant on fossil fuels is also likely to require less port capacity, fewer oil and gas tankers, and fewer hinterland railways to transport coal. On the other hand, digitalisation and smarter energy systems may require additional investment needs in telecommunication systems. G20 countries need to better understand the actual infrastructure investment needs associated with their low-emission development strategies.

Most existing energy and transport infrastructure was designed and built for a world in which fossil fuels were cheap and abundant. Given the long lifespan of infrastructure, failure to invest in the right type of infrastructure in the next 10 to 15 years would either lock the world into a GHG-intensive development pathway or risk stranding many assets. It would also imply serious and probably irreversible risks, not only of environmental damage, but also of financial instability that harms economic growth prospects. As explained above, the later a decisive transition begins in earnest, the more difficult and disruptive it promises to be for the energy sector and other GHG-intensive activities. Taking a low-carbon path offers an opportunity to accelerate investment in infrastructure, create a short-term boost to economic growth and development, and provide relief from persistent problems like congestion, air pollution and access to energy.

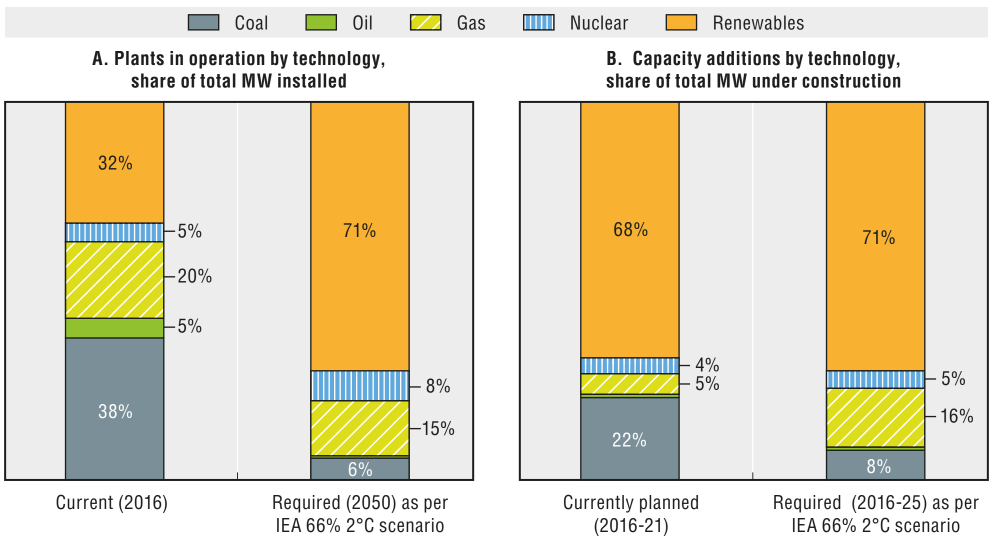
Improving the transparency of infrastructure project pipelines

While long-term planning is a vital first step for the low-carbon transition, G20 countries must also be able to transform such plans into bankable, low-emission infrastructure projects. Most countries still lack clear and transparent information on their infrastructure investment pipelines, even though G20 leaders recognised in 2014 the importance of such pipelines for tackling the global investment and infrastructure shortfall. Improving the visibility of infrastructure plans and needs is a key priority and critical to gain the confidence of private sector investors. Where current investment plans are known, they are often limited to the energy sector and generally not consistent with the commitment in the Paris Agreement to mitigate GHG emissions and support adaptation. In addition, G20 countries have a significant influence on infrastructure developments in other countries through export credits and official finance, where better alignment with the Paris Agreement should be sought.

New analysis of the current existing capacity and current pipeline of power plants in G20 countries[3] indicates that a shift towards investment in renewable energy has started and is likely to continue in the next 15 years, as two-thirds of the global capacity under construction is based on renewable energy technologies – close to what is required by the IEA 2°C 66% scenario (Figure 1.7, right-hand panel). Despite this encouraging trend, more than 20% of the projects under construction are still based on coal. This number could increase as 416 GW of coal plants are in pre-construction development, and 543 GW are on hold. Continuing this trend will put the temperature targets set out in the Paris Agreement out of reach.

Innovation will play an important role in achieving low-emission growth. While much progress can and needs to be made immediately using currently available technologies, a full low-carbon transformation will require widespread innovation and deployment of new infrastructure, technologies and business models. Beyond the need for new combinations of technologies to achieve net-negative emissions while meeting food demand sustainably, heavy industry will require technology breakthroughs to mitigate process emissions and to reduce reliance on fossil fuels. Energy sector innovation is also important, including rapid advances in energy storage to accommodate larger shares of variable renewable sources. As mentioned above, structural reforms can play an important role in facilitating this green innovation and ensuring that it is good for growth.

Figure 1.7. **Current capacity and current pipeline of power plants relative to those required in a 66% 2°C scenario**



Source: Authors' analysis from *i)* Platts WEPP (2017) for oil and gas under construction in G20 countries; *ii)* the Global Coal Plant Tracker (2017) for coal under construction in G20 countries; *iii)* IAEA (2016) for nuclear under construction in G20 countries; *iv)* IEA (2016b) for renewable energy under construction in G20 countries; and v) IEA (2017) for capacity additions in the IEA 2°C 66% scenario, globally.

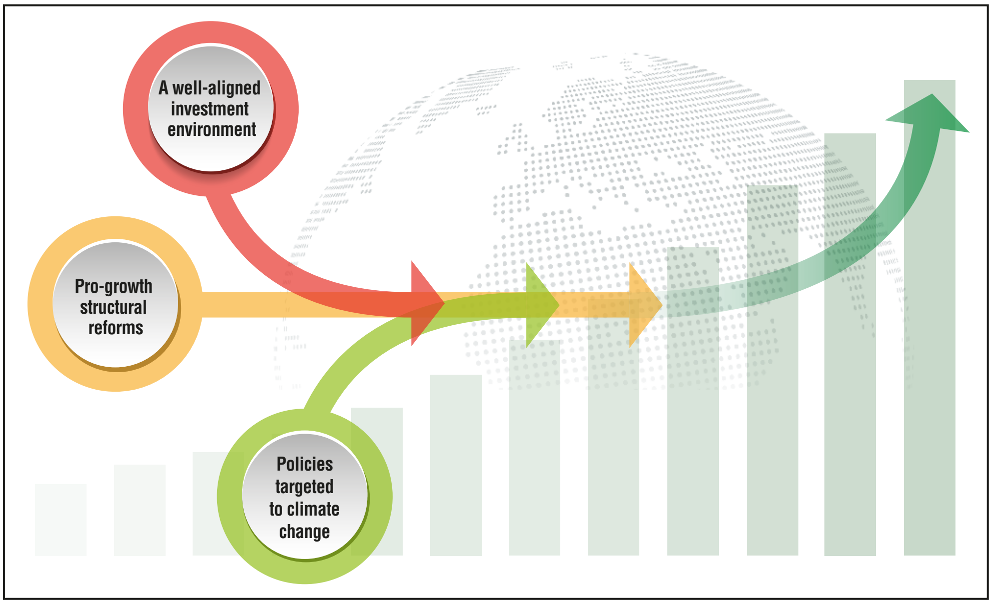
StatLink http://dx.doi.org/10.1787/888933484002

Combining pro-growth reforms with climate policy and well-aligned investment conditions

To mobilise the investment required for a decisive transition, governments need to support pro-growth structural reform policies with coherent climate policies and a well-aligned investment policy environment (Figure 1.8). The most effective policy combinations to mobilise investment in low-emission infrastructure vary from country to country, including the respective contributions of public and private investment.

Structural reforms that promote higher and more inclusive growth – such as measures to enhance product-market competition, facilitate access to jobs and improve skills – can be supportive of the low-carbon transition and are a key part of a decisive transition for climate and growth. The swift infrastructural, technological and industrial shifts implied by low-emission pathways to 2050 demand more rapid resource reallocation and faster technology diffusion. They can be further accompanied by improving dynamism in labour markets, provided that workers in the most affected carbon-intensive industries are supported through the transition. Pro-growth reforms that help meet these demands also generate more productive economic activity and enable new entrants to capitalise on emerging opportunities. Easier reallocation also boosts investment in R&D and other forms of knowledge-based capital, which boost adoption of new low-carbon technologies and long-term productivity growth. This requires reforms in product markets, financial markets, labour markets and housing markets. In short, policies that attempt to preserve the status quo – or at most favour an incremental transition – risk falling short from both a climate and an economic point of view.

Figure 1.8. **The three components of a well-aligned policy framework for climate and growth**



Strong and coherent climate policy as the basis for the transition

Carbon pricing can be a powerful, cost-effective tool for steering producers and households towards low-carbon and growth-oriented behaviour and investments. However, carbon prices have so far been low, especially when measured by "effective carbon rates" that incorporate the carbon price equivalent of energy taxes as well as explicit carbon prices. Currently, most CO_2 emissions within the G20 are not priced at all, and 91% are priced at less than EUR 30 per tonne of CO_2 (a conservative estimate of the lowest social costs that would result from a tonne of CO_2 emissions).

Where carbon prices exist, their impact on infrastructure investments has tended to be limited and indirect, partly because price signals have been weakened by transitional support measures or exemptions given to firms or households. Poorly targeted use of the public revenues from carbon pricing can also hinder their effectiveness and reduce the political acceptability of carbon pricing. On the other hand, intelligent use of carbon pricing revenues is an opportunity to improve fiscal space and make climate policy more inclusive and progressive, for example by reducing other taxes and lightening the burden on the poorest households.

Fossil-fuel subsidies are still widely prevalent and act as negative carbon price signals, leading to increased emissions of CO_2 and local pollutants. In 2014, G20 countries collectively provided subsidies amounting to USD 354 billion for fossil-fuel consumption, and USD 18 billion for fossil-fuel production. These subsidies translate into large fiscal costs for governments. For example, the fiscal burden of fossil-fuel subsidies reached as high as 1.4% of GDP in Mexico and 4.1% of GDP in Indonesia before both countries started reforming such subsidies; those subsidies were also regressive, benefiting mostly those on upper and middle incomes. In general, governments can make fossil fuel subsidy reform more acceptable if they precede such reform by improving energy services and introducing measures aimed at supporting the poor.

Even where carbon pricing is at the heart of countries' climate policy, local conditions and political compromises often make the design of schemes less than perfect and more susceptible to factors like information asymmetries, non-price barriers such as behavioural change, and public opposition to new taxes or tax increases. This means that carbon pricing may need to be complemented by other targeted measures such as specific investment incentives; regulations and standards; information policies; and measures aimed at low-carbon innovation. The interactions between policies need to be carefully evaluated, however.

Tuning broader investment conditions for low-emission, resilient investment

For climate policies to be more effective – and more supportive of low-emission economic growth in a decisive transition – the broader policy environment in which they operate needs to be well aligned with climate objectives. Existing policy frameworks, developed over decades to support fossil fuel-based economic growth, can inadvertently weaken the low-emission investment signal provided by carbon pricing. Potential misalignments can be identified in many policy areas, including investment, competition, trade and tax. A first priority is to ensure that pro-growth reforms are well aligned with low-carbon growth, such as ensuring a competitive level playing field for electricity generation. In addition, specific policies and regulations that weaken the business case for investment and innovation in low-emission and climate-resilient infrastructure need to be identified and fixed. For instance, poorly designed support schemes and outdated maps of domestic natural resources may hinder the attractiveness of investment in renewables. Inconsistent land-use and transport planning can lead to a locking in of carbon-intensive infrastructure and behaviour, particularly in urban areas.

Some land-use policies can also be misaligned with climate objectives. Resolving these conflicts is vital to maximise the contribution of the land-use sector to low-emission pathways while balancing land-use priorities. For example, agricultural input subsidies, price support, tariffs and subsidies on agricultural products, and in some cases subsidised crop insurance premiums, often foster more emissions-intensive practices and impede investments in adaptive technologies (though in some countries specific policy designs are aligned with sustainability objectives). Land degradation is another example, resulting from uncontrolled open access to common land. Reforming land tenure arrangements – to increase private ownership or long-term leases – or strengthening the sustainability of traditional institutions and land use rights, can foster private investment in restoring degraded landscapes or preventing land degradation, which in turn help sequester more CO_2.

Public infrastructure choices and procurement

Public procurement at central and local government levels plays a key role in the economy as a whole (averaging 13% of GDP in advanced countries, and sometimes more in emerging economies). It is particularly important for pro-growth infrastructure investment, including low-emission and resilient infrastructure. Public procurement can also create lead markets for innovative, low-GHG industrial materials and infrastructure choices. This can be done by pricing life-cycle CO_2 emissions in procurement criteria, thereby encouraging a competition to lower emissions. To unlock this potential and align procurement with Paris Agreement objectives, public procurement organisations need to be strengthened.

Efforts to improve climate resilience, in particular infrastructure resilience, need to take country and locally specific contexts into account. In general, the owners and operators of infrastructure are best placed to decide on the appropriate measures to implement. The public sector has a key role to play, however, to ensure that the current direction of infrastructure investment is aligned with the goal of increasing resilience to economic and climate-related shocks, and also catalysing private sector investment in adaptation by creating an enabling environment. A well-designed regulatory framework, information on climate risk and pricing externalities, and better aligned policies could help drive adequate investment in resilience by owners, operators and financiers.

A transition that is inclusive, progressive and good for business

Even though action on climate change can be positive for overall economic growth and welfare, most countries face political challenges in implementing ambitious policy reform. Vested interests and incumbent actors in today's high GHG-emissions societies can prevent governments from acting decisively and consistently. In a decisive transition, certain assets, especially in the fossil fuel and power sectors, will lose value and be economically stranded, with potential implications for employment opportunities. Even if the impact on overall employment is likely to be modest, jobs will shift as GHG-intensive activities change business profiles and technologies.

Most countries' economies are "entangled" with fossil fuels and other GHG-intensive sectors, reflecting the significant contribution of these activities to past economic development. Even in countries that are not fossil fuel producers, tax revenues, financial markets, pension funds and jobs depend to varying degrees on GHG-emitting activities, which can place governments in a position of significant conflict should they try to implement strong climate policies. This entanglement can render climate action ambivalent at best unless governments adopt an inter-ministry, cross-cutting approach to climate action.

Governments have previously had to learn about the modernisation and restructuring of some heavy industries, experience which may prove instructive in managing the transition to a less GHG-intensive economy, including engaging with affected firms and communities. Relevant measures used in the shipbuilding and iron and steel sectors include the creation of funds and targeted subsidies (e.g. restructuring investment aid, closure aid), special legislation and fiscal measures. Clearer decarbonisation and adaptation pathways will help governments anticipate, plan for and communicate the structural consequences of the transition away from GHG-intensive activities. This should minimise the destruction of asset values. Disruption linked to business cycles and other factors, such as the global excess capacity of iron and steel, can allow governments to prepare industry for the shift.

Creating opportunities for workers most affected by the low-carbon transition will be essential. The aggregate effect of the transition on jobs may be modest, but reallocation across sectors and activities will be necessary and in some sectors significant. Trade unions are aware of the challenges posed by the transition and advocate a role for workers in a "just transition" – a transition that includes proactive measures to plan and invest in environmentally and socially sustainable jobs, sectors and economies. Good planning to anticipate and facilitate retraining and mobility, and an active social dialogue between government, employers and workers, are vital for climate-friendly development.

The low-carbon transition will also directly affect households. Energy supply costs may increase, at least in the short term, so households could face transitional costs for new efficient equipment and infrastructure. Households could also face higher energy unit costs, for example where carbon pricing is the instrument of choice. These changes may be regressive, affecting the poorest households the most, but targeted recycling of carbon tax revenues can offset this effect. In many countries, the need to improve energy access and affordability will have a strong bearing on policy choices to facilitate the adoption of low-carbon energy practices. The reforms of fossil-fuel subsidies, initiated in some G20 countries and beyond, have shown how governments can compensate for rising energy prices and avoid regressive impacts.

The transition is unlikely to succeed, however, unless the low-carbon economy includes and provides opportunities to all actors. The transition will affect everyone, from central and local governments to the private sector, the labour force and citizens, whose divergent interests and influence will come into play. An improved understanding of aligned and divergent interests can help governments to make policy that addresses multiple needs and musters coalitions in favour of action – in business, institutions, civil society and different government portfolios. This would ensure that other pressing policy priorities, such as poverty alleviation and inclusiveness, are not compromised, making the transition more sustainable. This broad-based engagement should be an essential element in the domestic processes guiding the elaboration of low-greenhouse gas development strategies.

Overall, to improve the chances of achieving the Paris Agreement goals, it is vital to incorporate political economy considerations early in the process of elaborating domestic strategies to implement Nationally Determined Contributions. In addition, pursuing "whole-of-government" approaches to low-emission, climate-resilient growth can help governments to avoid entanglement in high-carbon sectors and activities.

Mobilising capital for a decisive transition

Coherent climate policy and a well-aligned investment framework are essential to steer the investment flows needed to pursue low-emission, resilient pathways, but in themselves are not enough. Mobilising the necessary capital also requires diverse financial instruments tuned for infrastructure financing, efficient allocation of risks and use of risk mitigation techniques, public financial institutions geared towards low-carbon investment, and a financial system that correctly values climate risk.

Private financing of infrastructure, including low-emission energy infrastructure, has undergone a major shift in the last decade. Renewable energy projects have been able to access more diversified pools of financing through project finance structures, attracting equity investors such as pension funds and sometimes project bonds. At the same time, banks are facing challenges such as non-performing loans and stricter regulation, so there is a need to open complementary sources of finance such as institutional investment and capital markets. The low-carbon transition will require substantially stronger efforts to overcome the remaining barriers to mobilising the private investment capital required for low-emission, resilient infrastructure.

New models and partnerships are scaling up financing for low-emission infrastructure, by drawing on the changing role of traditional financial actors and their respective strengths. Increased co-operation, for instance between banks and utilities, or between development finance institutions and institutional investors, has significant potential to facilitate finance for key elements of low-emission pathways, including renewables and energy efficiency in buildings and industry.

Real and perceived risks related to infrastructure financing, for example due to weak governance and regulation, currency fluctuations, and lack of domestic capital markets, continue to hamper private investment, particularly in emerging economies. There is also a need to improve the understanding of the specific risks and returns associated with investment in low-emission infrastructure. These risks often relate to infrastructure as an asset class, characterised traditionally by its long-term nature and high upfront costs, together with political, regulatory, macroeconomic and business risks and, more recently, climate change risks.

Despite the crucial role of technology and innovation, as highlighted in the pathways analysis above, new venture capital finance in clean technologies has been declining. Current investment models are not always aligned with the capital intensity and long development timelines required by clean technologies. Governments need to remove bottlenecks in clean technology finance, particularly in early stages and commercialisation, by enhancing public and private co-operation and improving business models for the financing of research and development in energy efficiency and low-emission infrastructure.

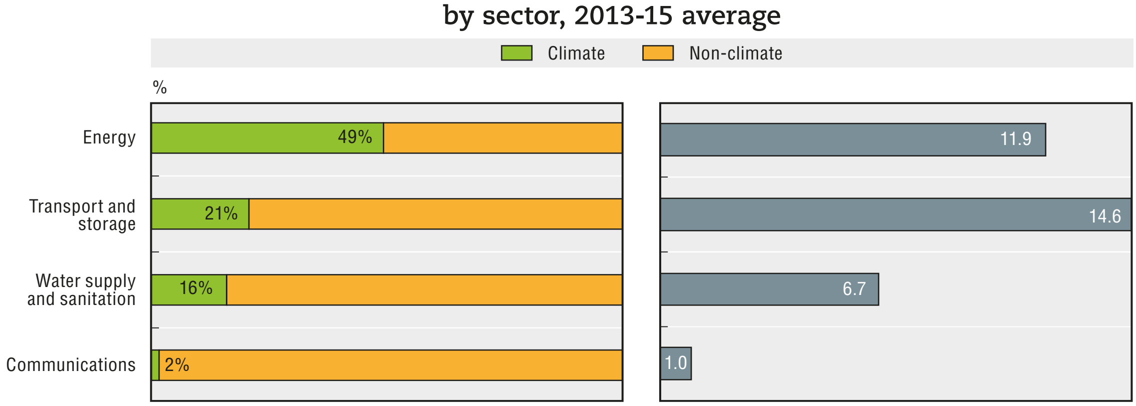
Various risk mitigation and "blended" finance approaches have been developed and need to be scaled up. Tools such as guarantees, credit enhancements, currency hedging and more diversified insurance offerings help to mitigate and better allocate risk across different actors, while instruments such as green bonds and securitised loans help to secure a reliable long-term funding basis for infrastructure projects. Blended finance models – with a focus on crowding in private finance – can de-risk and mobilise private investment in infrastructure, while optimising public investment.

Important role of development banks and finance

Development banks (national and multilateral) and development finance institutions (DFIs) have a critical role as a bridge between private and public actors, helping countries to embark on a sustainable low-carbon development path. National development banks (NDBs) are widespread in the G20, and several are initiating efforts to finance low-emission, climate-resilient infrastructure. Multilateral development banks (MDBs) and bilateral DFIs have made ambitious climate commitments and are scaling up efforts to mobilise private climate investment, while dedicating significant financing to infrastructure (Figure 1.9). MDBs are able to leverage significant capital through their shareholder governments and mobilise knowledge, expertise and innovation developed in other parts of the world. Despite this, MDBs could better align their financing for infrastructure with low-emission pathways, particularly in the transport and water sectors, by increasing the share of climate-related commitments in their portfolios, improving disclosure of portfolio-wide carbon impacts and renewing efforts to mobilise private investment. To meet their targets, MDBs and bilateral finance institutions require strong mandates. They also need to work with countries to raise awareness and build demand for low-emission, climate-resilient infrastructure, facilitated by access to concessional climate finance. Increased collaboration and joint action between MDBs, bilateral actors and NDBs will be needed to scale up financing, particularly in emerging and developing countries.

Governments also need to co-operate to guide the global financial system to more accurately value climate risk and move towards investment in low-emission and climate-resilient infrastructure. Fuller disclosure and reporting of climate impacts and risks is required to enable a broader shift in the financial system towards alignment with the Paris Agreement and the Sustainable Development Goals. Policies need to focus on the mainstreaming of climate-change risk management practices across the financial system, and the efficient pricing of assets based on disclosure of climate change risks. In spite of progress through the Financial Stability Board, public-sector finance institutions still lag behind, and individual country responses are uneven across the G20.

Figure 1.9. **Share of MDB commitments for infrastructure that are climate-related and total MDB commitments for infrastructure (USD billion) by sector, 2013-15 average**



Notes: This graph is based on data reported to the OECD Development Assistance Committee by the following MDBs: the African Development Bank, the Asian Development Bank, the European Bank for Reconstruction and Development, the European Investment Bank, the Inter-American Development Bank, the Islamic Development Bank and the World Bank Group (WBG), which also includes the International Finance Corporation. Climate-related components of projects are those that target mitigation, adaptation, or both mitigation and adaptation, based on the joint MDB Climate Finance Tracking Methodology. MDB commitments include concessional and non-concessional support.

Source: OECD DAC statistical system.

StatLink http://dx.doi.org/10.1787/888933484375

Main policy messages

The analysis above points to a wide array of policy priorities that G20 countries can adopt to launch a decisive transition, creating strong, inclusive economic growth while reorienting economies towards low-emission, climate-resilient pathways:

Integrate the climate imperative into structural reform and broader national development strategies, reflecting the role of our physical environment as a fundamental pillar for strong, sustainable, balanced growth.

- Implement **structural reform policies** that boost both productivity and economic activity, as well as supporting the transition to low-emission, climate-resilient economies, through easier resource reallocation; faster technology development and diffusion; greater dynamism in labour markets; and measures to facilitate firm entry and exit.
- Reassess and optimise **national fiscal policies** to increase investment in low-emission, climate-resilient infrastructure and soft investment such as climate-focused R&D, recognising the potential of fiscal measures to revive economic growth and strengthen climate-friendly investment signals.
- Continue to develop **relevant metrics and analytical tools** to incorporate the impacts of climate change and the costs of inaction into economic policy design and implementation, to move towards a more sustainable long-term growth model.
- Pursue a **whole-of-government approach** to low-emission, climate-resilient growth and address barriers and policy misalignments with climate objectives across the investment environment, particularly in infrastructure sectors, using the OECD publication *Aligning Policies for a Low-carbon Economy* as a starting point.
- Improve understanding and management of the interdependencies between **climate change and biodiversity conservation**, in relation to **food security, poverty alleviation and human health and well-being**, which are vital to achieving the Sustainable Development Goals.

Speed up collective and national efforts towards full implementation of the Paris Agreement.

- **Jointly commit to advancing the international stocktaking and oversight mechanisms of the Paris Agreement**, including those on monitoring, reporting and review, and the robust assessment of collective progress, to encourage deeper international co-operation and more ambitious action and support.
- Develop and share experience of **long-term, low-emission development strategies**, and ensure Nationally Determined Contributions and near-term actions are consistent with such strategies. These strategies should address climate and economic development objectives in an integrated way, shaping expectations about the scale and nature of investment needs and helping minimise stranded assets.

Recognise that for growth to be sustainable it must also be inclusive, and ensure that policies to drive the transition towards a low-emission, climate-resilient economy are socially progressive.

- Integrate the **social and economic implications of the transition** more effectively into policies and planning. Support sectoral restructuring by identifying exposed labour forces, communities and regions, by assessing local capabilities, and by developing response measures, including retraining and reskilling of the exposed workforce.

Adopt flexible, forward-looking approaches to decision-making to increase climate resilience and ensure that these approaches are robust given the uncertainty surrounding climate changes effects at local and regional levels.

- Establish a **pipeline of infrastructure projects** that are consistent with long-term, low-emission development strategies, reconciling short-term action and long-term decarbonisation goals, as a means to **shift investment** to climate-resilient infrastructure
- **Bridge data gaps on infrastructure projects** and improve information on investment pipelines, for example with the support of the G20 Global Infrastructure Hub and the OECD.
- Introduce specific policies and regulations, such as spatial planning and technical standards, that promote **climate resilience of infrastructure**, including screening and factoring climate risks in public investments, including procurement procedures.

Realise GHG mitigation potential across the economy.

- Accelerate the **reform of inefficient fossil-fuel subsidies** that encourage wasteful consumption, including agreeing on a date for phasing out such subsidies. As the basis for reform, expand internationally comparable information on subsidies to more countries and types of support, for example through peer review. Share experience on successful and progressive subsidy reforms.
- Broaden the carbon pricing base, track impact and emissions reductions progress, and share policy experience of **effective carbon pricing** to inform flexible forward-looking policy decisions. Explore joint action in this area, such as minimum carbon prices, gradual increases in prices over time, and linking of emissions trading systems.
- Tap the **large mitigation potential in agriculture, forestry and other land-use sectors**. Preserve and expand existing carbon stocks in forests and other ecosystems; avoid net deforestation and forest degradation; and improve soil management, in particular of organic soils. Stimulate mitigation in the agriculture sector by increasing investment in the development and deployment of new technologies and sustainable practices. **Promote efficient and effective use of nitrogen fertilisers and limit their over-use**.
- Make greater use of **public procurement** to invest in low-emission infrastructure and to trigger industrial and business model innovation through the creation of lead markets, for example by introducing climate-related criteria to procurement decisions.
- **Implement and strengthen research, development and demonstration efforts** for breakthroughs in technologies essential for eliminating GHG emissions from industry and from road, maritime and air transport, as well as breakthroughs in energy storage and “negative emissions” technologies, including through international collaborative efforts such as Mission Innovation.

Mobilise financing for the transition.

- **Expand efforts to mobilise private investment** in low-emission, climate-resilient infrastructure by scaling up the use of diversified risk mitigation tools, improved environmental risk analysis, and diversified financial instruments and models.
- Take steps towards a **more climate-consistent global financial system** by assessing and addressing possible misalignments within financial regulations and practices, improving the ability of markets to price climate change risks, and assessing the risks climate change poses to financial stability.
- Call on all development banks and finance institutions – multilateral, bilateral and national – to put in place targets and action plans to boost support for low-emission infrastructure and climate-proofing efforts; improve disclosure of climate risks; scale up efforts to mobilise private investment; and continue to support policy and planning frameworks for climate-resilient infrastructure, especially in vulnerable countries.

Notes

1. The carbon budget from 2015 to 2100 is smaller than this for the same likelihood of remaining below 2°C, requiring negative emissions after the peak. See Chapter 2.
2. The IEA (2017) assumptions, which this report builds on, are therefore conservative in this regard.
3. The electricity sector is the only sector where enough information is available to analyse the pipeline, as surveys and commercial databases track information on capacity in operation, cancelled, announced or at pre-construction stage, as well as under construction.

References

Booz Allen Hamilton (2007), *The global infrastructure investment deficit*, Booz Allen Hamilton, McLean, Virginia.

Global Coal Plant Tracker (2017), *Global coal plant tracker,* http://endcoal.org/tracker/.

IAEA (2016), *Power Reactor Information System*, International Atomic Energy Agency, Vienna, https://www.iaea.org/pris/.

IEA (2017), Chapters 1 and 2 in *Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System*, International Energy Agency/OECD Publishing, Paris, www.energiewende2017.com/wp-content/uploads/2017/03/Perspectives-for-the-Energy-Transition_WEB.pdf.

IEA (2016a), *Energy Technology Perspectives 2016*, IEA/OECD Publishing, Paris, http://dx.doi.org/10.1787/energy_tech-2016-en.

IEA (2016b), *IEA Medium-Term Renewable Energy Market Report 2016: Market Analysis and Forecasts to 2021*, IEA/OECD Publishing, Paris, http://dx.doi.org/10.1787/renewmar-2016-en.

OECD (2012), *Strategic Transport Infrastructure Needs to 2030,* OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264114425-en.

OECD (2006), *Infrastructure to 2030: Telecom, Land Transport, Water and Electricity*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264023994-en.

Platts WEPP (2017), *World Electric Power Plants Database,* Platts, London, www.platts.com/products/world-electric-power-plants-database.

WEF (2015), *The Global Competitiveness Report 2015-2016,* World Economic Forum, Geneva, www3.weforum.org/docs/gcr/2015-2016/Global_Competitiveness_Report_2015-2016.pdf.

Woetzel, J. et al. (2016), *Bridging Global Infrastructure Gaps,* McKinsey Global Institute, www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/bridgingglobal-infrastructure-gaps.

World Bank (n.d.), World Development Indicators, World Bank, Washington DC, http://data.worldbank.org/data-catalog/world-development-indicators.

Chapter 2

Pathways from Paris

Human interference with the climate system is rapidly taking us into uncharted territory, with the potential for severe and irreversible impacts and making it harder to achieve the Sustainable Development Goals (SDGs). The Paris Agreement aims to limit average global warming to well below 2°C, a political judgement based on scientific evidence. The stringency of this mitigation goal means that countries need to strengthen mitigation action without delay. After setting out the case for urgent action and the carbon budget consistent with the goal of well below 2°C, this chapter examines the characteristics of low-emission pathways and how country diversity may impact the scale, phasing and priorities for mitigation action across countries. It then summarises projected impacts, emphasising the need for flexible, forward-looking approaches to decision-making that reflect the diversity of climate vulnerabilities and confidence levels about local and regional change. Finally, the chapter looks at how countries can get to where they need to be, supported by the mechanisms of the Paris Agreement.

This chapter sets out the case for urgent action on climate change and explains in broad terms what is required to move to low-emission, climate-resilient development pathways. The first section explains why we need to act urgently. The second section assesses the carbon budget consistent with the "well below 2°C" goal in the Paris Agreement, and how this in turn depends on developments in the non-energy sector – notably in agriculture, forestry and land-use (AFOLU). The third section examines the characteristics of low-emission pathways, taking as its core a scenario consistent with a 66% likelihood of keeping the global average surface temperature increase to below 2°C throughout the century (IEA 66% 2°C scenario) from a parallel report for the German G20 Presidency on the scale and scope of energy sector investments needed to increase the chances of reaching this goal (IEA, 2017). This section also analyses the IEA 66% 2°C scenario in the context of a broader range of scenarios achieving similar outcomes. The fourth section then examines how country diversity may affect low-emission pathways and the priorities for action across countries. Even with stringent mitigation, climate change is projected to have significant negative impacts, so countries need to enhance resilience and increase their adaptive capacity. The projected changes in regional and local conditions are far less well understood than larger-scale changes in temperature, sea-level rise and ocean acidification.[1] The fifth section summarises projected impacts and emphasises the need to develop flexible, forward-looking approaches that help us to identify robust solutions. The last section of this chapter addresses the key question of how countries can get to where they need to be from where they are now, highlighting the fundamental importance of the Paris Agreement in building trust and transparency to underpin effective international action.

Climate change – why we need to act urgently

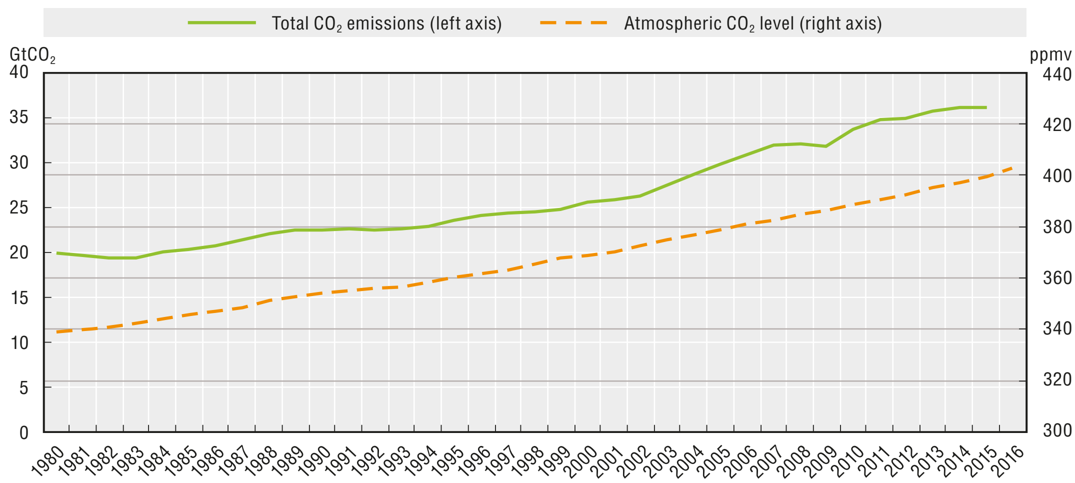
The last 60 years or so have seen unprecedented human impact on the systems that underpin life on Earth (Steffen et al., 2004). Industrial-scale agriculture and the massive use of fossil energy to drive economic growth have transformed the life chances of billions of people.[2] But they have also created an unpredictable climatic future, very different from the conditions in which humanity has thrived for the past 10 000 years. Since 1990, world GDP has more than doubled while carbon dioxide (CO_2) emissions from fossil fuel use have increased by some 60%, contributing to increasingly rapid climatic change (Figure 2.1).

Other environmental challenges have also emerged, such as ozone depletion, biodiversity loss, desertification, and local and regional pollution. Rapid progress on reducing ozone depletion has been possible, underpinned by international agreements targeting ozone depleting chemicals. Other "wicked" problems have proved more resistant to progress (Rittel and Webber, 1973). Notable among these is climate change, which both poses profound challenges to our current development paradigm and, at the same time, opens up opportunities for sustained and sustainable improvements in inclusive economic well-being.

Climate change in context

Global atmospheric concentrations of CO_2 – the major greenhouse gas (GHG)[3] – have now risen past 400 parts per million (ppm by volume) from a pre-industrial level of around 280 ppm (Figure 2.1). By 2012, the global mean surface temperature had increased by approximately 0.85°C on average from pre-industrial levels;[4] each of the last three decades has been successively warmer than any preceding decade since 1850 (IPCC, 2014a). In 2015, global mean temperatures went 1°C above pre-industrial levels for the first time, due to the combined effects of climate change and a very strong El Niño that lasted into early 2016. All but one of the 16 warmest years on record has occurred since 2001, with 2016 the hottest recorded (WMO, 2017).

Figure 2.1. **Global CO_2 emissions from fossil-fuel use and cement production, and the atmospheric concentration of CO_2**



Sources: *i)* CO_2 emissions from Olivier et al. (2016); *ii)* Global atmospheric CO_2 concentrations from NOAA (2017).

StatLink http://dx.doi.org/10.1787/888933484019

So where might we be heading? Projections of climate change depend on inherently uncertain assumptions about human behaviour and future policy choices. It is also difficult to estimate the precise strength of the climate response to atmospheric GHG concentrations, due to the complexity of the climate system.[5] Scenario analysis has therefore been a vital analytical tool in helping us understand the range of plausible future outcomes and how these depend on future emissions of GHGs and atmospheric aerosols, land-use change, and many other socio-economic factors.

Table 2.1 shows end-of-century projections for global mean surface temperature relative to pre-industrial levels (1850-1900) from the most recent assessment by the Intergovernmental Panel on Climate Change (IPCC), for four Representative Concentration Pathways (RCPs) (IPCC, 2013).[6] The scenario associated with the lowest emissions, RCP2.6, is consistent with a policy target of limiting warming to below 2°C with greater than 66% likelihood, broadly in line with the IEA 66% 2°C scenario (IEA, 2017). None of the other RCPs deliver mean surface temperature changes of 2°C or lower.

Table 2.1. **Projected mean temperature changes relative to a pre-industrial (1850–1900) baseline**

Emissions scenario	Change in mean temperature (°C) by 2081-2100
Low scenario – RCP2.6	1.6
Medium scenario – RCP4.5	2.4
Medium to high scenario – RCP6.0	2.8
Very high scenario – RCP8.5	4.3

Note: The temperature changes for each RCP include an observational estimate of warming of 0.61°C between 1850-1900 and 1986-2005 and the mean warming across CMIP5 Global Climate Models between 1986-2005 and 2081-2100 for the RCP. Both the observed historical warming and GCM-derived components of the changes have uncertainties. These are not presented as methods are not generally available in the literature for combining the uncertainties in models and observations.
Source: IPCC (2013).

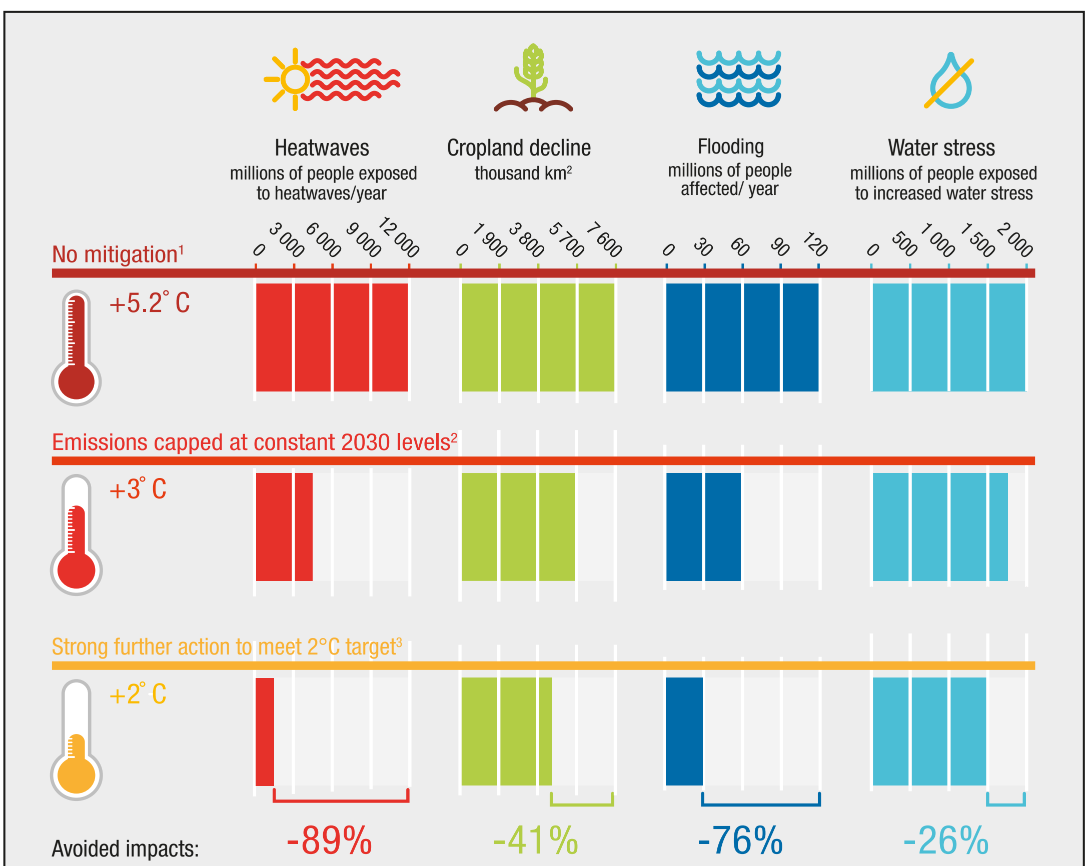
Climate risks and the benefits of mitigation

Climate change will lead not just to higher temperatures but also to rising sea levels, acidification of the oceans – with effects on marine ecosystems – and changing patterns of precipitation, as well as more extreme weather. Regions will be affected differently by these changes; regional (and smaller-scale) changes in weather patterns and precipitation are still highly uncertain (see for example, Shepherd, 2014). Changes could even take us beyond thresholds or "tipping points" in the climate system (Box 2.1). Greater levels of emissions will therefore lead to a greater likelihood of "severe, pervasive and irreversible impacts" (IPCC, 2014b).

Stringent mitigation action to limit temperature increases would moderate the physical climate impacts that countries would otherwise need to adapt to (Figure 2.2). With climate change, heat waves are likely to become more frequent and longer in duration; keeping the global average temperature increase to 2°C will significantly limit the number of people exposed to heatwaves. Similarly, climate change is very likely to increase extreme precipitation events in some regions (IPCC, 2013). Mitigation could moderate the increase in the number of people exposed to flooding, as well as limiting loss of cropland and reducing water stress.

Climate change is projected to destroy human and physical capital. How these changes translate into economic terms is an open research challenge, depending on potentially non-linear interactions between climate, ecological and social systems, as well as infrastructure networks (see Box 2.1 and Chapter 4). This makes climate change a risk management problem: the approach needs to be one of finding the most cost-effective ways to limit climate risks to a politically agreed level, informed by the best scientific evidence. Early and ambitious action on adaptation and mitigation can significantly reduce these risks.

Figure 2.2. **Estimates of climate change impacts avoided by 2100 through mitigation**



Notes: (1) Refers to RCP8.5 scenario. (2) Emissions capped 55.1 $GtCO_2e$, consistent with the NDCs, with no backtracking. (3) Strong further action for a 50% chance of meeting the 2°C target: emissions of 55.1 $GtCO_2e$ in 2030, with further large reductions in GHG emissions to meet 2°C by 2100.

Source: AVOID2 (2015).

Box 2.1. **Thresholds for abrupt and/or irreversible change**

The level of scientific understanding of thresholds in the climate systems, as well as the physical and economic implications of crossing such thresholds, is low. Such potential changes include the collapse of the Atlantic Meridional Overturning Circulation (AMOC), the disappearance of summer Arctic sea ice, ice sheet collapse, permafrost carbon release, methane release, and tropical and boreal forest dieback.

Recent research has given greater confidence to evidence that partial irreversible loss of the West Antarctic Ice Sheet has already begun. Tropical forests are being adversely affected by drought, while AMOC weakening continues. Interaction between different thresholds will be important in determining the timescales, extent and reversibility of changes throughout the climate system. For example, increased meltwater from ice sheets will further weaken the AMOC, and this may in turn alter the position of the Intertropical Convergence Zone near the equator, affecting rainfall patterns and the health of the Amazon rainforest (Lenton et al., 2008).

Figure 2.3. **Examples of thresholds for abrupt and/or irreversible climate impacts**

Note: There is considerable uncertainty relating to the reversibility of climate impacts. Here, impacts are considered irreversible if recovery is unlikely within 100 years after climate drops back below the relevant threshold.
Source: MOHC analysis of *i)* IPCC, 2014c and *ii)* AVOID2 WPA.5 Report.

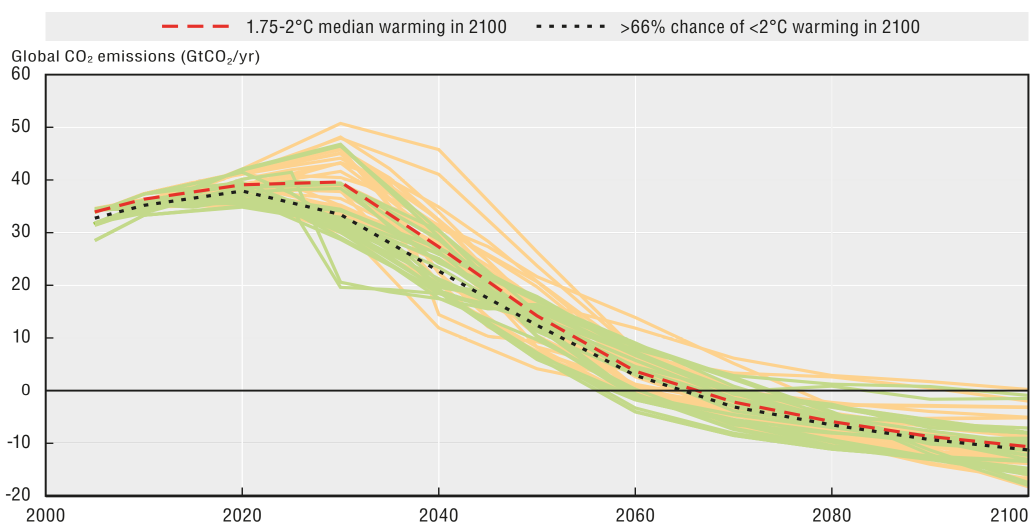
What does the Paris Agreement mean for carbon budgets?

The interpretation of "well below 2°C"

The Paris Agreement reached at the 21st Conference of the Parties to the UNFCCC (COP21) in December 2015 aims to hold the global average surface temperature increase to "well below 2°C and to pursue efforts to limit it to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change" (UNFCCC, 2015a). There is, however, no precise definition of what "well below 2°C" means.

It is not immediately obvious that the IEA 66% 2°C scenario used in the related IEA report (IEA, 2017) should be equated to a "well-below 2°C" goal. However, UK Meteorological Office Hadley Centre (MOHC) analysis of the many scenarios analysed as part of the IPCC's AR5[7] suggests that in general, scenarios delivering a greater than 66% likelihood would be somewhat more stringent in terms of emissions reductions than scenarios consistent with 1.75-2.0°C of median warming by 2100 (Figure 2.4). Most of these stringent IPCC mitigation scenarios (the thin coloured lines in Figure 2.4) rely on net negative CO_2 emissions, whereas the IEA 66% 2°C scenario assumes no net negative emissions. It is therefore reasonable to use the IEA 66% 2°C scenario as one representation of what a well-below 2°C scenario could look like, though of course there are other plausible pathways that could include net negative emissions.

Figure 2.4. **IPCC AR5 CO_2 emissions scenarios with a greater than 66% chance of staying below 2°C**



Source: IPCC AR5 Database, MOHC analysis.

StatLink http://dx.doi.org/10.1787/888933484028

Carbon budgets and temperature goals

CO_2 is the predominant GHG, but many other gases contribute to global warming (Box 2.2). For long-lived GHGs, such as CO_2, it is the cumulative level of emissions over time that determines the contribution to climate change, not just the emissions in a given year. There is a strong linear relationship between cumulative CO_2 emissions and the increase in average surface temperatures (Wigley, Richels and Edmonds, 1996; Allen et al., 2009; IPCC, 2013; Friedlingstein et al., 2014). This means that there is an upper limit on the total cumulative CO_2 emissions over time consistent with a given temperature target – the so-called "carbon budget". This budget is not a single number but a range, reflecting uncertain projections about the emissions of non-CO_2 GHGs, as well as in the climate response to GHGs in the atmosphere.[8]

Box 2.2. **Greenhouse gases, aerosols and radiative forcing**

Climate change is due to a net imbalance in the energy flowing into the Earth system due to human modifications of the atmosphere. CO_2 is responsible for most of the warming observed since the pre-industrial period (1.68 ± 0.035 Watts per metre squared (W/m^2) in 2011 relative to 1750), but other gases play an important role in this "radiative forcing" – tipping the balance of radiation flowing into the Earth's atmosphere.

- Atmospheric concentrations of methane (CH_4) reached 1,810 parts per billion (ppb) in 2012, 2.5 times more than in 1750. Even at these small concentrations, CH_4 has contributed about 20% of the radiative forcing of CO_2 (Ciais et al., 2013).
- Atmospheric nitrous oxide (N_2O) is another important GHG, with a radiative forcing of 0.17 ± 0.03 W/m^2 in 2011 compared with the pre-industrial period. Concentrations have risen more than 20% since pre-industrial times, mostly due to increased agricultural activity, with a lesser contribution from the burning of fossil fuels and industry (Ciais et al., 2013).
- Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) contribute approximately 11% of the total radiative forcing from GHGs and also deplete stratospheric ozone (O_3). Emissions of CFCs have been drastically reduced in recent years as the Montreal Protocol has been implemented, but due to their long lifetime it will take a substantial amount of time to affect atmospheric concentrations.
- The effect of atmospheric ozone (O_3) depends on where it is situated. In the lower atmosphere, O_3 is formed when other chemical species, such as CH_4 and carbon monoxide, combine with nitrogen oxides (NOx) in sunlight, contributing to poor air quality. Stratospheric O_3 has a small cooling effect, but overall ozone has a warming effect of around 0.35 (0.15 to 0.55) W/m^2 (Myhre and Shindell, 2013).
- Aerosols are microscopic particles suspended in the atmosphere that generally cool the climate, yet some have a warming effect (e.g. black carbon). IPCC AR5 (IPCC, 2013) estimated the radiative forcing of aerosols to be -0.9 (-1.9 to -0.1) W/m^2 (Myhre and Shindell, 2013), an overall cooling effect on the climate. Aerosols and their interactions with clouds offset a substantial portion of global mean warming, but aerosols contribute the largest uncertainty to the total radiative forcing estimate.
- Land use change from human activity also affects the Earth's climate, by changing the surface albedo (how much light it reflects) and by increasing the emission of GHGs (e.g. through deforestation). Afforestation also absorbs CO_2 from the atmosphere. Land use change has significant impacts on the local water cycle and can lead to changes in rainfall in regions far away from the initial land use change (e.g. DeAngelis et al., 2010).

Carbon budgets consistent with 2°C and 1.5°C temperature targets are shown in Table 2.2, along with an indication of the likelihood of limiting warming to this level. These budgets assume non-CO_2 GHG emissions contribute the equivalent of around 420 gigatonnes of CO_2 ($GtCO_2$) (Rogelj, 2016b). The global carbon budget compatible with a greater than 66% likelihood of staying below 2°C is estimated to be 590-1 240 $GtCO_2$ from 2015 to the time of peak warming (Rogelj, 2016b). This represents roughly 15 to 30 years of fossil fuel-related CO_2 emissions at current rates – an indication of the remarkably short time remaining in which to transform the global energy system and to meet the Paris Agreement's temperature goal. Even this challenging number assumes net negative CO_2 emissions later in the century. The carbon budget to limit the temperature increase to 2°C with a 66% likelihood by 2100 is more stringent – between 470 and 1 020 $GtCO_2$.

This downwards adjustment reflects the fact that to achieve such a stringent mitigation target, modelling suggests that it would be more cost-effective to reduce emissions at a slightly lower – but still rapid – pace early on and then to compensate with "negative emissions" later in the century. Drawing CO_2 back down from the atmosphere and sequestering it safely over the long term enables such scenarios to live within their carbon budgets.[9] The most plausible options for achieving this are afforestation, bioenergy with carbon capture and storage (BECCS) and changed agricultural practices (Box 2.3).

The total carbon budget used in the IEA 66% 2°C scenario is 880 $GtCO_2$. This budget lies below the mid-point of the "peak warming" range (915 Gt CO_2) and above the mid-point of the range for the entire period 2015-2100 (745 Gt CO_2). The IEA 66% 2°C scenario assumes no net negative emissions. Out of this total budget of 880 $GtCO_2$, the IEA allocates a carbon budget of 790 $GtCO_2$ for the energy sector, and assumes that 90 $GtCO_2$ over 2015-2100 are emitted from industrial processes. Land use is assumed to generate approximately net zero cumulative emissions over the period, starting from positive emissions and becoming negative by the end of the century. Non-CO_2 GHGs are assumed to contribute around 0.5°C of warming by 2100 (IEA, 2017).

Table 2.2. **Carbon budgets from 2015 to peak warming for different temperature targets and likelihoods**

Temperature targets	>50% < 2°C	>66% < 2°C	>50% 1.5°C
Global carbon budget available from 2015 to peak warming (Gt CO_2)	990-1 240	590-1 240 [470-1 020]+	390-440

Note: Figures represent 10th-90th percentile range. The budget to peak warming may include negative emissions, but not any net negative emissions required after peak warming. +This denotes the global carbon budget over the whole period 2015-2100, taking account of net negative emissions after the peak.
Source: Adapted from Rogelj, 2016b; IPCC, 2014c.

Box 2.3. **What are negative emissions?**

Owing to the long time scales involved in the removal of carbon from the atmosphere by natural processes, recovery from an overshoot of the atmospheric CO_2 concentration may take a considerable amount of time (Lowe et al., 2009; Solomon et al., 2009). Technologies that actively remove carbon from the atmosphere – resulting in "negative emissions" – could be used to lower atmospheric CO_2 in the event of an overshoot in emissions, but could also be important in offsetting emissions from sectors where emissions reductions are more difficult (such as freight, aviation and shipping). Several options have been examined for negative emissions technologies (NETs):

- **Afforestation and reforestation (AR)** to fix atmospheric CO_2 in terrestrial biomass and soils. Potential is estimated at 4 $GtCO_2$/yr at a lower cost than BECCS and with land and nutrient requirements increasing with potential (Smith et al., 2015).
- **Changed agricultural practices (CAP)**, such as soil management practices that can improve soil quality by reducing soil erosion and increasing resilience to weather variability, while simultaneously contributing to food security objectives (OECD, 2015e). Soil carbon sequestration and biochar each have the potential to provide about 2.6 $GtCO_2$eq/yr and have fewer disadvantages than many NETs (Smith, 2016).
- **BECCS:** Farming bio-energy crops that absorb CO_2 as they grow and are then burnt for energy, with the resulting emissions captured and stored underground. Potential is estimated at around 12 $GtCO_2$/yr (Smith et al., 2015).
- **Direct air capture (DAC):** The use of chemicals to absorb CO_2 from the atmosphere before being stored in solid form or pumped into geological reservoirs. Potential is estimated at around 12 $GtCO_2$/yr but at a far greater cost and energy requirements than BECCS (Smith et al., 2015).

Box 2.3. **What are negative emissions?** *(cont.)*

- **Enhanced weathering (EW):** Natural weathering of minerals is accelerated to remove CO_2 from the atmosphere, with the products stored in soils or buried in the land surface. Potential is estimated at around 0.7 $GtCO_2$/yr (Smith et al., 2015).
- **Ocean fertilisation (OF):** Increasing the ocean's biological uptake of CO_2 by fertilising nutrient-limited areas.

These NETs each have large but varied levels of uncertainty over their social acceptability, unresolved technological issues and high costs, and variable demands for land, water, energy and fertiliser, which affect their feasibility and efficacy at scale (Smith et al., 2015). DAC is considered to have very high costs and energy requirements. EW is also a high-cost technology as well as having a limited global potential for emissions removal and significant requirements for land use. OF by contrast is seen as too risky as little is known about the ecological effect of dumping large quantities of nutrients into the sea (Schiermeier, 2007), nor does it do anything to address ocean acidification. AR and BECCS are typically the only NETs included as mitigation options in current generations of Integrated Assessment Models. The extent to which these technologies can be deployed at scale in the near- to medium-term is a key uncertainty.

Low-emission pathways

Characteristics of low-emission pathways

As can be seen from Figure 2.4 and the tight constraint on carbon budgets consistent with limiting temperature change to well below 2°C, low-emission pathways will be characterised by the following broad features:

1. A peak in global emissions as soon as possible;
2. A subsequent rapid fall in GHG emissions, particularly of CO_2 emissions;
3. Net GHG emissions approach zero or even become net negative in the second half of the century (IPCC, 2014a).

The later the peak in global CO_2 emissions, the greater the rate of emission reduction required subsequently to be consistent with the carbon budget. Options for achieving stringent mitigation goals may be lost if the peaking level is too high or too late. Delaying peaking beyond 2020 would make the Paris Agreement's goal of well below 2°C significantly more difficult to achieve, requiring even more rapid reductions of emissions and a prolonged period of net negative CO_2 emissions through major afforestation or the large-scale use of negative emissions technologies such as BECCS (Box 2.3). Action will need to come earlier and the fall-off in emissions will need to be more rapid if even more stringent targets are to be achieved (e.g. towards 1.5°C). Not reaching a global emissions peak before 2030 may preclude limiting warming to well below 2°C.

Assumptions for future non-CO_2 GHG emissions constrain the carbon budget available for the energy sector and industrial processes.[10] While CO_2 emissions will eventually need to go to zero, or below, annual emissions of short-lived GHGs such as CH_4 only need to be stabilised and can still remain positive while meeting the goal of well below 2°C (Allen et al., 2016). The higher the level at which such emissions are stabilised, however, the lower the carbon budget consistent with a given temperature goal will be (Allen et al., 2016).[11] For N_2O, a long-lived GHG, it is the cumulative level of emissions over time, not the level of emissions in a given year that matters most for maximum temperature change (Smith et al, 2012).

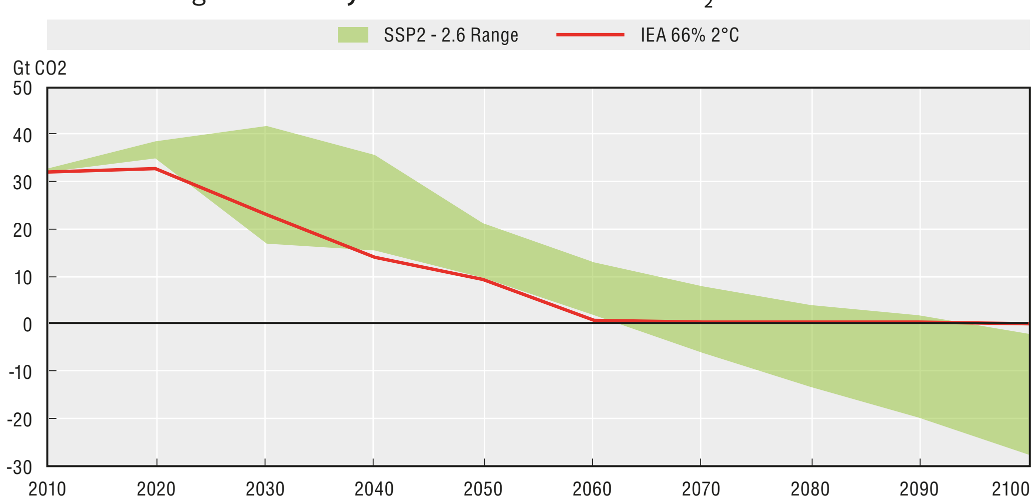
N_2O emissions are predominantly due to agriculture.[12] Population and economic growth are increasing demand for food, so N_2O emissions will continue for the foreseeable future to ensure food security, even if we can improve the efficiency of fertiliser use (Zhang et al., 2015). As a long-lived GHG, continued N_2O emissions would need to be offset by a reduction of other long-lived GHGs – for example, by greater negative emissions of CO_2.

The IEA pathways in context

Socio-economic developments, including economic and population growth and food demand, will influence whether future GHG emissions will be consistent with a well below 2°C target. The Shared Socio-Economic Pathways (SSPs, Riahi et al., 2017) provide a set of storylines exploring the implications of different assumptions about future economic growth, demographics and technical change. Together with the IPCC's RCPs, they provide a framework to analyse and evaluate the implications of climate policy in different socio-economic settings. In this section, the IEA 66% 2°C scenario is compared with modelling results[13] for a "middle-of-the-road" SSP scenario (SSP2), coupled with the IPCC's RCP 2.6 scenario (together, SSP2-2.6).[14]

Figure 2.5 shows the evolution of non-land-use CO_2 emissions for the IEA 66% 2°C scenario alongside the SSP2-2.6 comparison range. The IEA emissions numbers encompass both energy-related emissions and industrial process emissions:[15] the IEA non-land use CO_2 emissions pathway lies at the lower edge of the range of the SSP mitigation scenarios to 2050. The IEA's assumption of no net negative CO_2 emissions means that to meet the carbon budget constraint, emissions must peak earlier and lower than in the scenarios that do allow net negative emissions. The range of non-land-use CO_2 emissions in SSP2-2.6 becomes negative by the end of the century, due to extensive use of BECCs. The IEA 66% 2°C scenario rules out net negative CO_2 emissions and lies at the upper end or above the SSP2-2.6 range at the end of the century. Its lower CO_2 emissions early on allow the IEA scenario to still remain below 2°C with a 66% likelihood.

Figure 2.5. **Projections of non-land use CO_2 emissions**



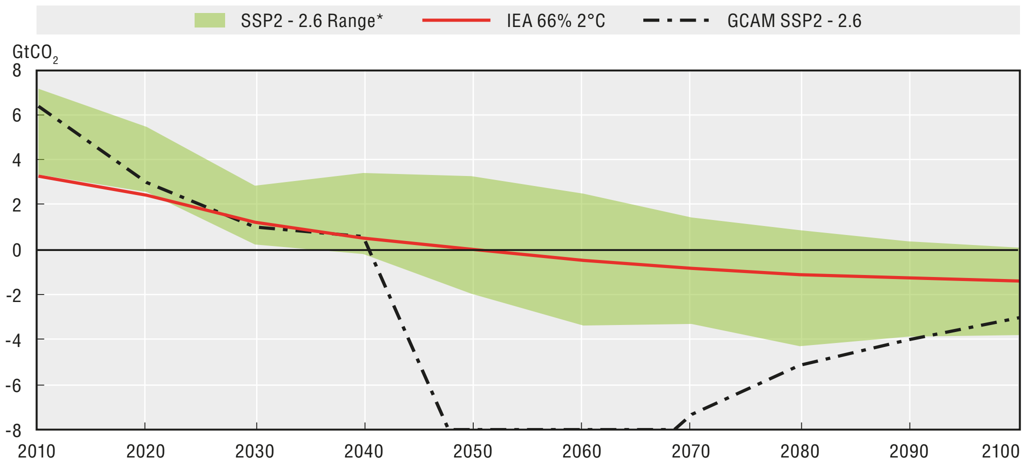
Source: IIASA (n.d.) and IEA (2017).

StatLink http://dx.doi.org/10.1787/888933484038

Figure 2.6 provides a similar comparison between the IEA and SSP scenarios for CO_2 emissions from land-use change. Land use in the IEA 66% 2°C scenario turns from a source to a small sink by 2050 and emissions lie well within the range of emissions in the SSP2-2.6 modelling results. The outcomes of one particular modelling realisation of SSP2-2.6 (the

GCAM model) display extreme changes in land-use emissions due to strong dependence on afforestation and the use of bioenergy (at different times) as mitigation options, which leads to steep projected increases in food prices towards the end of the century (Popp et al, 2017).[16]

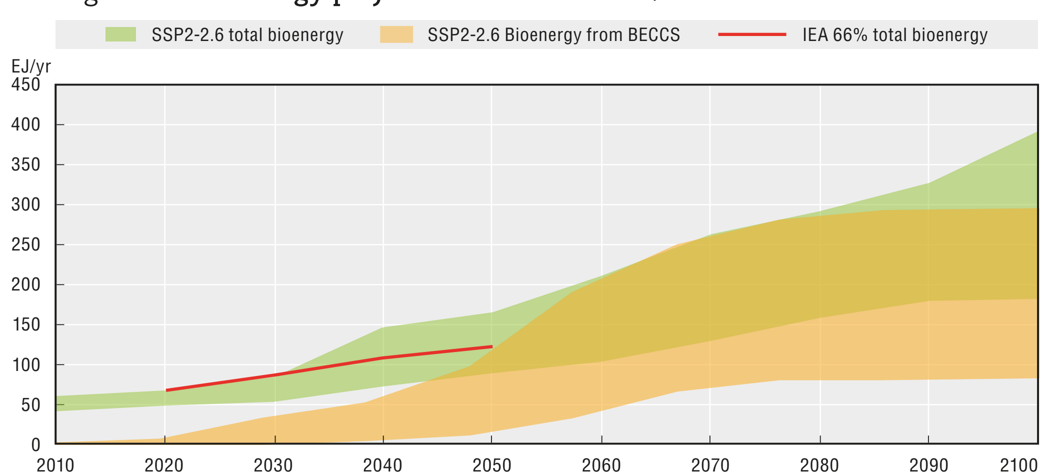
Figure 2.6. **Projections of land-use change CO_2 emissions**



Notes: *SSP2 range excluding GCAM results.
Source: IIASA (n.d.) and IEA (2017).
StatLink http://dx.doi.org/10.1787/888933484042

Since the IEA land-use assumption aligns better with the other model realisations of SSP2-2.6, the IEA scenario would seem to be consistent with much smaller projected increases in food prices to 2100. This conclusion is further strengthened by examining projections for total bioenergy in energy demand in these different scenarios. Again, the IEA projections for total bioenergy demand align closely with the SSP2-2.6 range to 2050 as shown in Figure 2.7. In all the SSP2-2.6 scenarios, energy from traditional biomass is projected to fall sharply after 2020, while BECCS increases rapidly. The IEA assumes a modest amount of BECCS in 2050 (about 2 exajoules (EJ)/yr in the power sector), which increases the pressure on the energy system to decarbonise earlier and faster, including through the extensive use of CCS in the industrial sector (IEA, 2017)

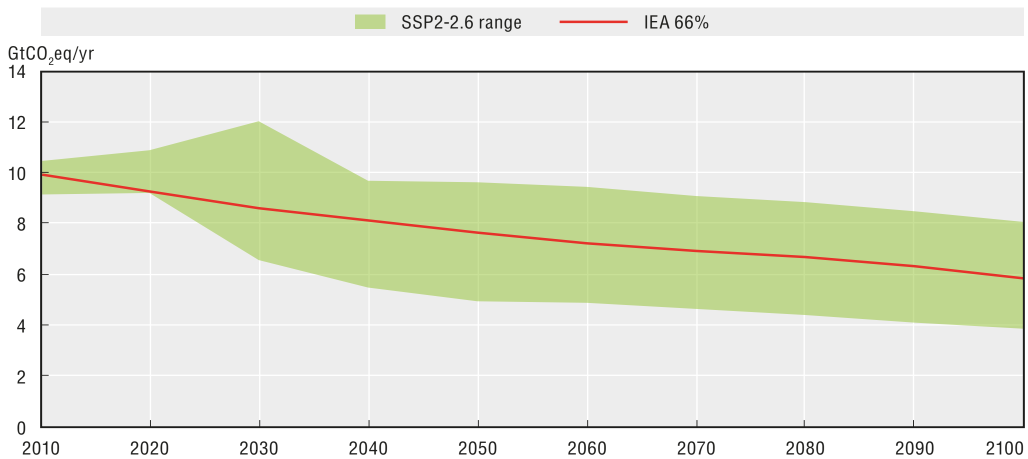
Figure 2.7. **Bioenergy projections in the IEA 66% and SSP2-2.6 scenarios**



Source: IIASA (n.d.) and IEA (2017).
StatLink http://dx.doi.org/10.1787/888933484052

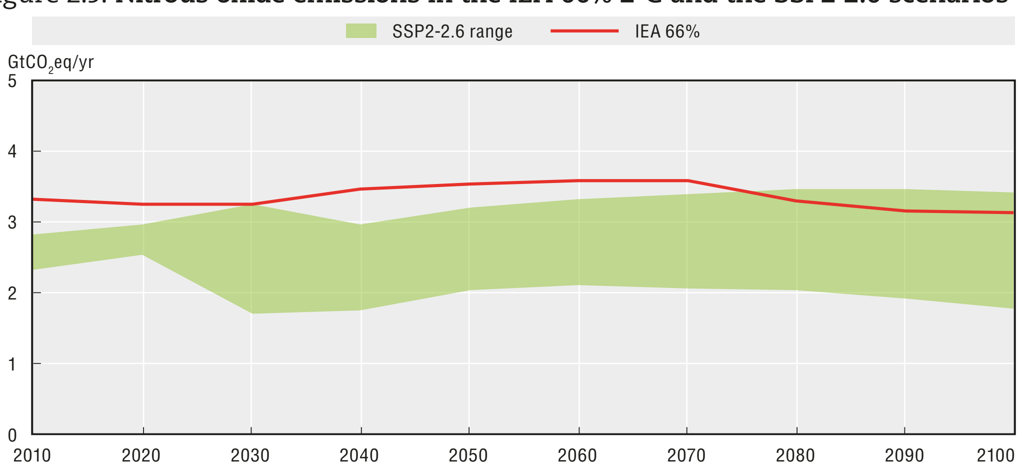
Turning to the main non-CO_2 GHGs, Figures 2.8 and 2.9 compare the range of CH_4 and N_2O emissions in the IEA 66% 2°C and the SSP2-2.6 scenarios. There is a wide range of projections and a much wider range still if we consider less stringent mitigation outcomes or other future socio-economic storylines. Any lack of progress in mitigating emissions to this level – particularly of N_2O – would clearly reduce the chances of staying below 2°C, or require offsetting net negative emissions through afforestation, BECCS or another approach.

Figure 2.8. **Methane emissions in the IEA 66% 2°C and SSP2-2.6 scenarios**



Note: uses a GWP 100 value for CH_4 of 28 (Table 8.7 of IPCC (2013)).
Source: IIASA (n.d.).
StatLink http://dx.doi.org/10.1787/888933484069

Figure 2.9. **Nitrous oxide emissions in the IEA 66% 2°C and the SSP2-2.6 scenarios**



Note: uses a GWP 100 value for N_2O of 265 (Table 8.7 of IPCC (2013)).
Source: IIASA (n.d.).
StatLink http://dx.doi.org/10.1787/888933484072

Priorities and challenges ahead

The transformation of the energy and industrial systems over the next decades is absolutely fundamental to achieving the Paris Agreement's goal of well below 2°C and will require major structural change to overcome the carbon-intensity that is hard-wired into economies, systems and behaviours (IEA, 2017). That transformation needs to be effected within a few decades if serious climatic disruption is to be avoided. While much progress can and needs to be made now based on currently available technologies, we will also need to develop new technologies and infrastructure to bring us within reach of the very low or negative emissions required by the second half of the century.

Outside the energy and related end-use sectors, the extent of GHG emissions from AFOLU sectors will set the pace and nature of the transition needed in the energy sector. Additionally, mitigation options within the AFOLU sectors may be the critical determinant of whether these stringent mitigation scenarios are feasible, notably afforestation and avoided deforestation[17], bioenergy, BECCS and more GHG-efficient and productive agriculture. Availability of bioenergy is uncertain; estimates suggest it could account for 3% to 37% of the global energy share by 2050, and 23% to 50% of the global energy share by 2100 in a 2°C scenario, with models projecting more than half of modern biomass primary energy coming from non-OECD countries (Rose et al., 2014). The bioenergy share in the IEA 66% 2°C scenario falls within this range, as it does in IRENA's comparable scenario where bioenergy accounts for around 21% of total final energy consumption by 2050, growing from 13% today. Developments in AFOLU are highly uncertain, however, and depend on many factors including technical progress, demographics and demand side developments, such as dietary preferences (Box 2.4).

Box 2.4. **Competing priorities for land**

A central issue for the future of AFOLU emissions is how the demands for food production and for climate mitigation are managed. Food demand is projected to grow strongly through the century along with population and economic growth. The United Nations Food and Agriculture Organisation (FAO) estimates indicate that to meet the demand projected for 2050, global agricultural production must grow 60% above the level of 2005-07 (FAO, 2013). In parallel to increasing food production, reducing food losses and waste "from field to fork" would ease environmental pressures and climate impacts by improving efficiency along the food supply chain (OECD, 2016b).

Over the last five decades (between 1961-63 and 2007-09) agricultural production has increased by 170%. Increased agricultural demand has so far been met largely through improvements in yield (which accounted for 80% of the agricultural production increase), rather than land expansion (20% of the production increase) (OECD, 2012). But the rate of yield growth for most crops has been decelerating in the past few decades, even though it is still increasing in absolute terms (FAO, 2013). So without further yield improvements, demand for agricultural land is likely to grow, increasing the associated CH_4 and N_2O emissions. On the other hand, improving growth in agricultural Total Factor Productivity (TFP) through increased research, development and innovation has the potential to meet demand for food production while using fewer environmental resources and inputs, and emitting fewer GHGs (OECD, 2014). The AFOLU sectors could even become a net sink for CO_2 before the end of the century (IPCC, 2014a).

The demand for bioenergy for climate mitigation could grow rapidly through the century (Figure 2.7), raising questions about both the compatibility of large-scale bioenergy production with food security, and the sustainability of bioenergy in terms of life-cycle emissions and impacts on water and ecosystems, which will vary depending on the particular bioenergy technology and where and how it is applied.

Uses of bioenergy include fuels to replace fossil fuels, particularly in aviation and freight, heating for industrial processes, and as an input to negative emissions technologies (Box 2.3), such as BECCS. If deployed at sufficient scale, this sort of technology could deliver two major economic benefits: i) allow the transition to low-emission technologies to be more gradual than otherwise would be necessary; and ii) offset emissions from any sectors in which mitigation proved technically, economically or socially too difficult.

The greater the scale at which bioenergy is used and produced, however, the greater the tension with food security objectives, in the absence of demand-side measures such as dietary changes that reduced the relative demand for meat products, and reduced food waste (Smith et al., 2013).

Negative emissions technologies and other bioenergy uses will clearly affect other aspects of the Sustainable Development Goals, such as food production, water availability and biodiversity (Smith et al., 2013). The feasibility and acceptability of BECCS is uncertain, in terms of deployment of CCS technologies (see Chapter 6), as is the availability of arable land to meet the simultaneous demand for food production and for biomass for energy (Box 2.4). The IPCC AR5 mitigation scenarios consistent with a less than 2°C target require 210 $GtCO_2$ of BECCS annually by 2050 – which is of the same order of magnitude as the natural terrestrial and ocean carbon sinks – with cumulative global negative emissions typically up to 1,000 $GtCO_2$ over the century (Fuss et al., 2014). The sustainability of bioenergy feedstock is also a significant concern, in particular to guarantee a net zero carbon footprint. There is some degree of consensus among experts that the technical potential for sustainable bioenergy – the potential that is theoretically available before cost considerations are taken into account – is around 100 EJ per year (Creutzig et al., 2015).

In terms of energy use, the priority is to achieve rapid and transformational improvements in:

- *energy efficiency*, from the use of more efficient equipment, such as improved motors or internal combustion engines, from energy-efficient buildings and power plants, and from greater resource efficiency across the life-cycle of products (Box 2.5);
- *emissions intensity of energy*, by replacing emissions-intensive generation capacity and fuels with low-emission generation sources such as wind or solar, and the use of biofuels where they have a low life-cycle of emissions.

Box 2.5. **The importance of resource efficiency for climate goals**

Since 1990, the global use of material resources has grown broadly in line with global GDP, though slightly less rapidly. Global material resource consumption is projected to double by 2050 (OECD, 2016a). GHG emissions from the waste sector typically account for a few percent of total GHG emissions in OECD member countries, but this only represents direct emissions primarily from landfill methane emissions and incinerators. Resource efficiency improvements through an approach of "reduce, reuse and recycle" can support climate mitigation objectives and contribute to achievement of some of the SDGs.

The energy requirements and GHG emissions associated with the production, consumption and end-of-life management of materials can only be assessed by taking a systems view of the production of goods and fuels, transportation of goods, crop and food production and storage, and disposal of food and waste. The life-cycle GHG emissions arising from material management activities were estimated to account for 55% to 65% of national emissions for four OECD member countries, suggesting significant potential to reduce emissions through material resource efficiency measures (OECD, 2012). Substituting secondary, recycled materials for primary materials can significantly reduce GHG emissions (Table 2.3).

Table 2.3. Relative energy and carbon intensity of primary and secondary metal production

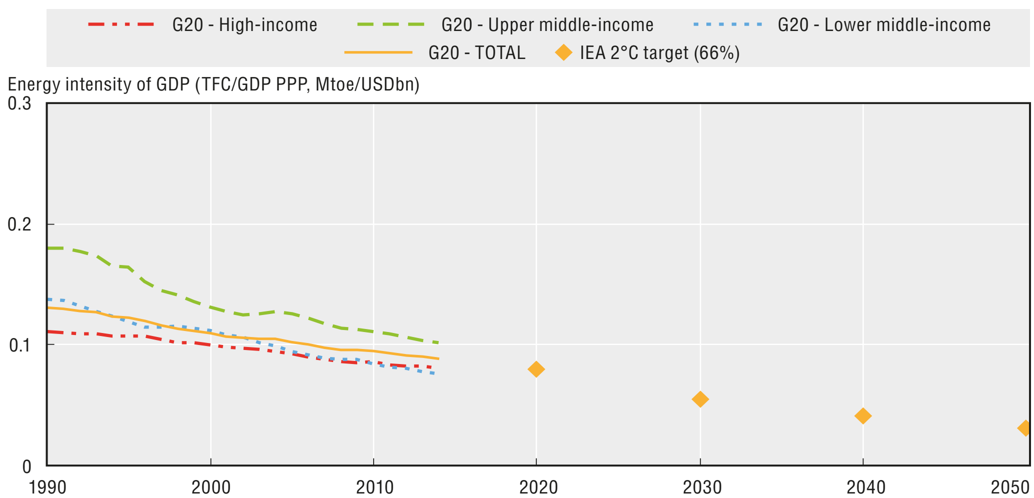
Material	Primary Energy TJ/100,000t	Secondary Energy TJ/100,000t	Primary CO_2 ktCO2/100,000t	Secondary CO_2 ktCO2/100,000t
Aluminium	4 700	240	383	29
Copper	1 690	630	125	44
Ferrous	1 400	1 170	167	70
Lead	1 000	13	163	2
Nickel	2 064	186	212	22
Tin	1 820	20	218	3
Zinc	2 400	1 800	236	56

Source: International Bureau of Recycling, 2008

Economic and population growth and increased fossil fuel use have been the main drivers behind the approximately 60% increase in global CO_2 emissions since the early 1990s. Global CO_2 emissions from energy use have increased less rapidly than GDP and energy use per unit of GDP globally has fallen by around 31%. However, at the same time, the CO_2 intensity of energy actually increased by 3%. Figures 2.10 and 2.11 show the historical performance of G20 countries on these two key measures compared with the levels projected in the IEA's 66% 2°C scenario.

The IEA estimates that the energy intensity of G20 economies would need to fall by more than 60% between 2014 and 2050 (IEA, 2017), a rate of around 3% a year from 2020 to 2050. Daunting as this sounds, it is broadly in line with historic achievements by the G20 countries. More challenging is the more than 75% reduction in CO_2 intensity of energy that is simultaneously required, an average rate of 4.4% a year from 2020 to 2050. Here historic trends are far less encouraging: achieving this scale of change will require an unparalleled increase in the deployment of low-carbon technologies (IEA, 2017).

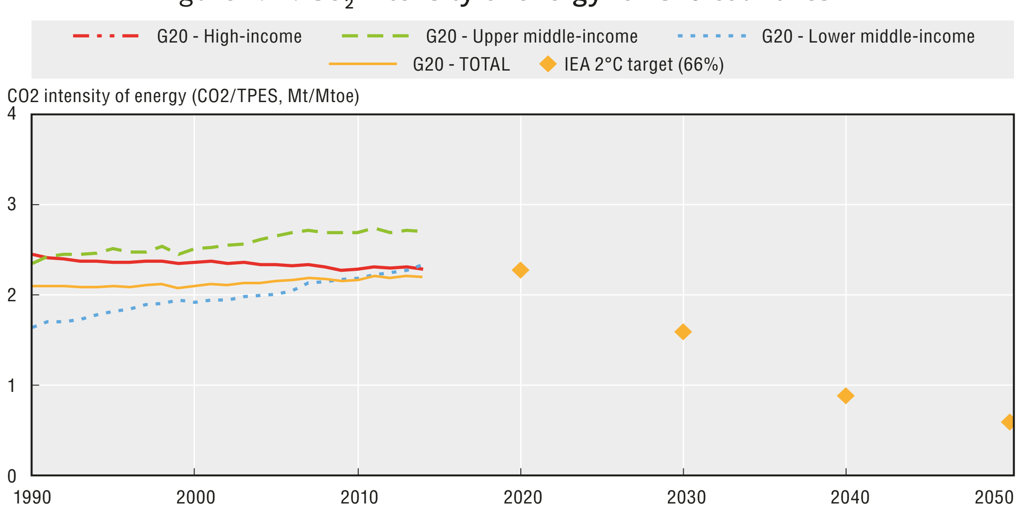
Figure 2.10. **Energy intensity of GDP for G20 countries**



Source: World Bank (n.d.a.) and IEA (2017).

StatLink http://dx.doi.org/10.1787/888933484083

Figure 2.11. **CO_2 intensity of energy for G20 countries**



Source: World Bank (n.d.a.) and IEA (2017).

StatLink http://dx.doi.org/10.1787/888933484095

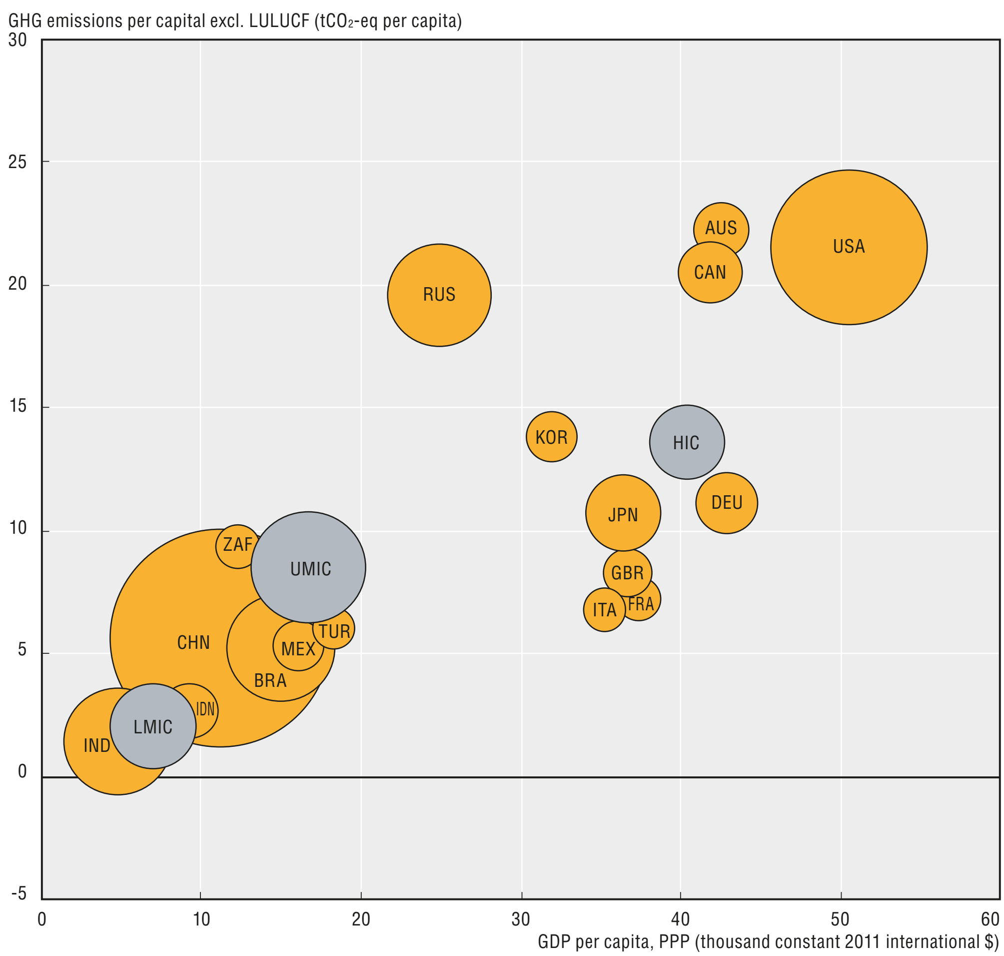
Country diversity and mitigation action

Absolute emissions reflect not just per capita income but also the size of the economy, its energy intensity and the CO_2 intensity of its primary energy supply (see above). Countries also have different income and population growth rates. These drive energy demand and future GHG emissions, as well as influence development patterns, climate resilience and adaptation capacities. Emissions from different sectors also have varying levels of importance from country to country. Finally, governance is an important factor in formulating and implementing low-emission, climate-resilient development pathways. This section analyses some of these key dimensions of country diversity.

Income levels, emissions per capita and governance

The capacity of each country to develop low-emission pathways depends on two key dimensions of country diversity: income level (GDP per capita) and average GHG emissions per person. In Figure 2.12, the size of each bubble represents the absolute level of emissions for the G20 countries (in orange), and the average emissions per G20 country included in each income group (in grey).[18] Emissions per capita are strongly correlated with GDP per person, reflecting the importance of energy to development.

Figure 2.12. **GHG per capita and GDP per capita in G20 countries, 2012**



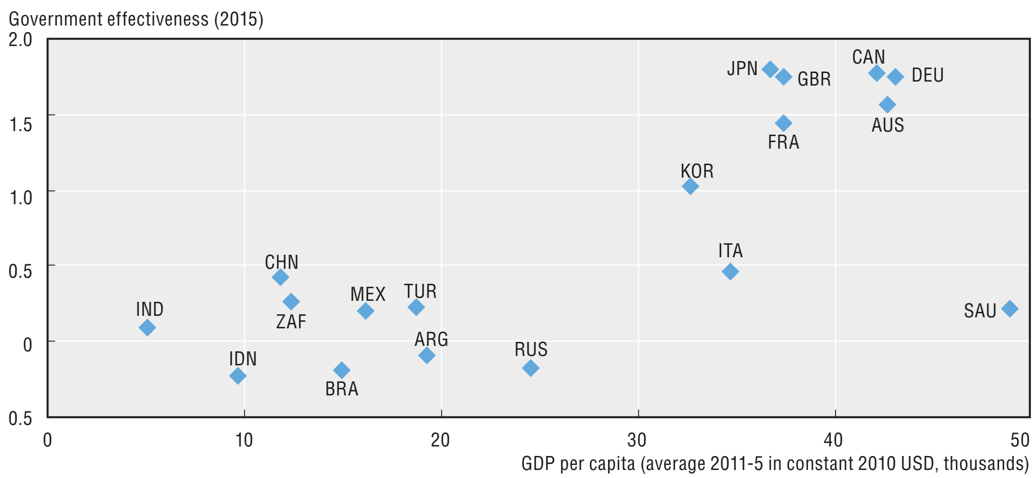
Note: Total GHG emissions in kilotonnes of CO_2 equivalent excluding land-use, land-use change and forestry (LULUCF). Values for 2012 except for Saudi Arabia (2011) and South Africa (2007). Bubble size is proportional to total GHG emissions for countries and average emissions for income groups. HIC= High-income countries, UMIC= Upper middle-income countries; LMIC= Lower middle-income countries.

Source: UNFCCC (2016), World Bank (n.d.a.), and replies to the OECD State of the Environment Questionnaire (accessed through OECD-STAT).

StatLink http://dx.doi.org/10.1787/888933484104

Income captures many dimensions of country capacity to mitigate and to adapt to climate change. More developed economies have higher levels of accumulated physical and human capital, financial and technological resources, and institutional capacity. Higher income levels are also highly correlated with standards of governance, as illustrated in Figure 2.13, which shows the results of a cluster analysis using six governance indicators and GDP per capita, and displays the results against just one of these, government effectiveness. Governance is a key factor underpinning effective and equitable adaptation across multiple actors and sectors in a context of uncertainty and complexity (Huitema et al., 2016). High income is also associated with greater levels of resilience, through mechanisms such as social safety nets, widespread insurance and infrastructure.

Figure 2.13. **Government effectiveness and GDP per capita**



Note: Government effectiveness is an index based on World Bank data and OECD calculations.
Source: World Bank (n.d.b.) and OECD calculations.

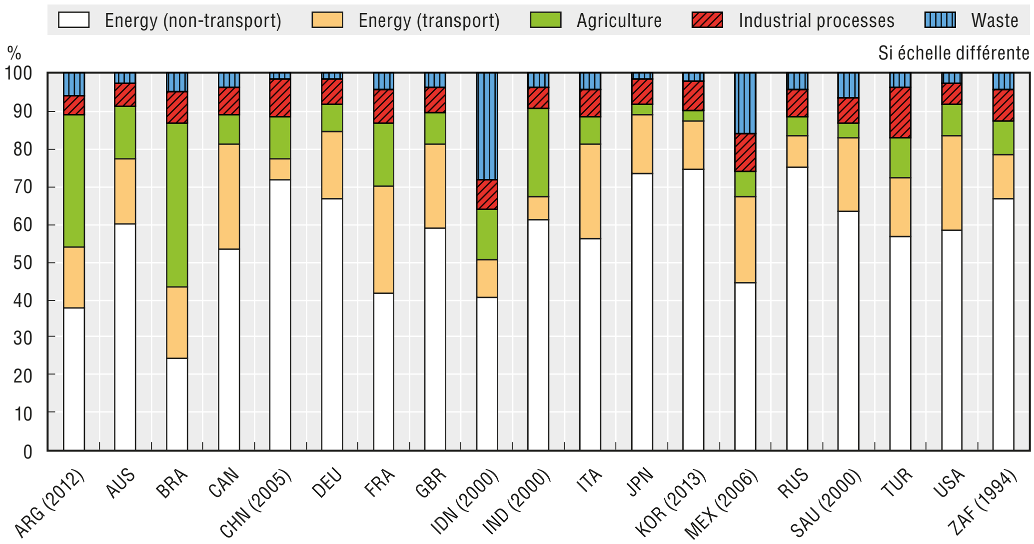
StatLink http://dx.doi.org/10.1787/888933484116

Structure of GHG emissions across the G20

Energy emissions represent the bulk of GHG emissions in G20 countries. However, emissions from other sectors make a significant contribution to overall GHG emissions, notably in Argentina, Indonesia and Brazil (Figure 2.14). Agricultural emissions are a significant proportion of emissions in Argentina, Australia, Brazil, France, India and Indonesia, and are important in several others. Hence countries will face choices over the phasing and timing of mitigation action in different sectors and on different GHGs, with early action on long-lived GHGs essential to avoid cumulative emissions incompatible with the Paris Agreement's goal of well below 2°C. Action on short-lived GHGs and other climate forcers can not only complement this but also provide significant benefits in terms of health and food security (Shindell et al., 2012).

Land-use emissions are also important. Figure 2.15 shows the relative importance of agricultural and land use, land-use-change and forestry (LULUCF) emissions, as a percentage of total GHG emissions including LULUCF across G20 countries.[19] Argentina, Brazil and Indonesia stand out, with a large share of one or both of agricultural and LULUCF emissions. In a number of countries, the sink capacity of land use (essentially negative emissions) more than offsets agricultural emissions,[20] while for three countries, combined LULUCF and agricultural emissions comprise 15% to 20% of total GHG emissions.[21] Land-use change related to commercial agricultural expansion is one of the major sources of CO_2 emissions from deforestation (Hosonuma et al., 2012), though the share of agricultural emissions is not strongly correlated with land-use emissions.

Figure 2.14. **G20 GHG emissions by sector (% of total GHG emissions excluding LULUCF)**

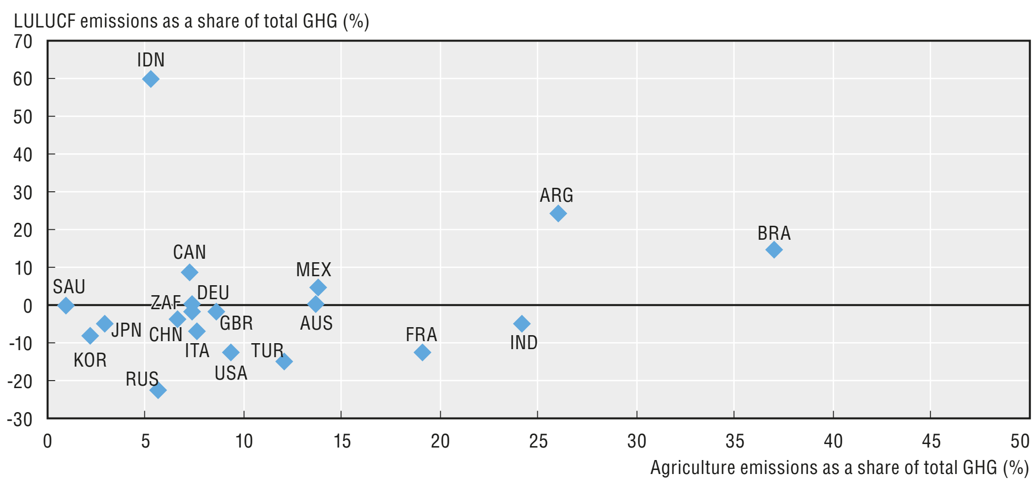


Notes: 1. 2014 or latest year available. 2. Emissions for Argentina, Mexico, and Saudi Arabia from UNFCC GHG profiles. Emissions for Brazil from MCTI, 2016.

Source: Data by sector from OECD, 2017; UNFCCC, 2014; MCTI, 2016.

StatLink http://dx.doi.org/10.1787/888933484129

Figure 2.15. **G20 agriculture, land-use and forestry emissions as % of total GHG emissions**



Source: UNFCCC (2016), World Bank (n.d.a.), and replies to the OECD State of the Environment Questionnaire (accessed through OECD-STAT), FAO (2016).

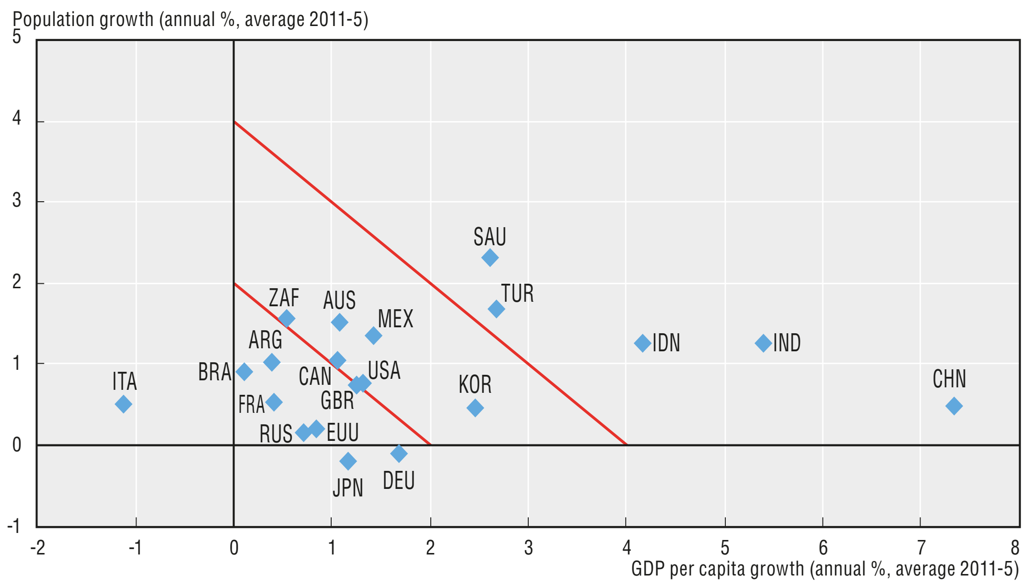
StatLink http://dx.doi.org/10.1787/888933484130

GDP, population growth and emissions

Future growth rates of energy-related emissions can be broken down into the growth rates of several different factors, including energy intensity of GDP and CO_2 intensity of energy (Blanco et al., 2014; Peters et al., 2017). So for a given rate of reduction in emissions, changes in GDP per person and in population together determine how quickly the other factors need to fall to keep on track to meet the Paris Agreement's goal of well below 2°C (Figure 2.16). Over the long term, GDP per capita growth rates may change as countries develop, but the current rates will influence the immediate challenges for countries in developing their low-emission, climate-resilient pathways. Countries such as Brazil that have experienced volatile economic growth rates, with sharp declines in growth in recent years, may change their relative position significantly. However, we expect the broad patterns to show some degree of stability over the period to 2030.

Countries fall broadly into three groups. In Brazil, France, Germany, Italy, Japan and Russia, recent combined growth rates in income per person and population are less than 2% per year. A second group of countries has combined growth rates between 2-4% per year, including Australia, Canada, Korea, Mexico, South Africa and the United Kingdom. A third group, including China, India, Indonesia, Saudi Arabia and Turkey, have combined growth rate in GDP per person and population of more than 4% per year.

Figure 2.16. **Growth rates of GDP per person and population in G20 countries, average 2011-15**

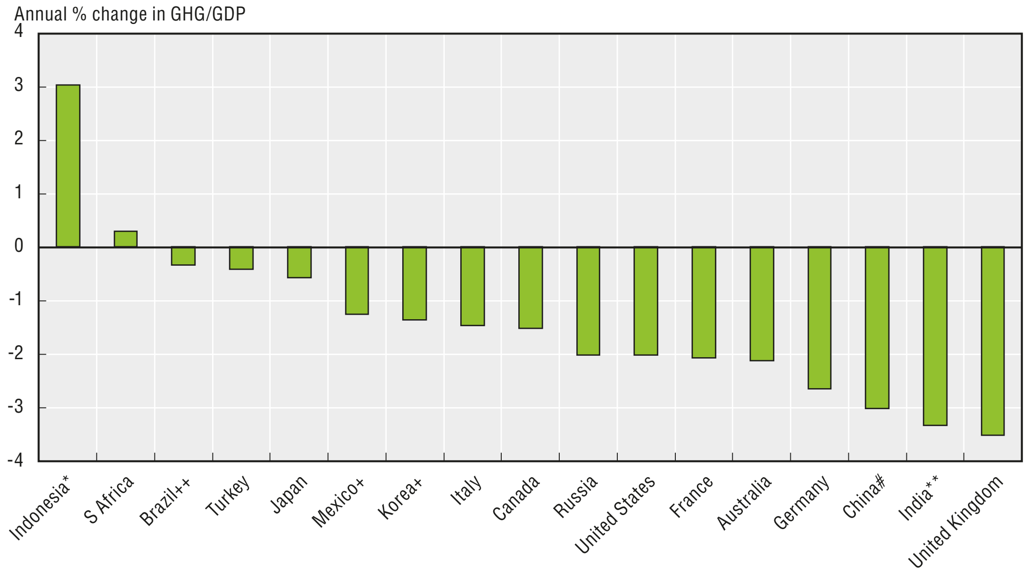


Note: Averaged over the most recent five years of data.
Source: World Bank (n.d.a).
StatLink http://dx.doi.org/10.1787/888933484141

If countries were aiming at a uniform rate of reduction in energy-related CO_2 emissions, the severity of the mitigation challenge would increase from the first to the third group. However a key element of the Paris Agreement is that countries' mitigation contributions reflect "common but differentiated responsibilities and respective capabilities in the light of different national circumstances", which is reflected in the nature and level of ambition embodied in countries' Nationally Determined Contributions (NDCs) (see section below).

However, even countries with rapid GDP or population growth can make rapid reductions in emissions per unit of GDP. GHG emissions per unit of GDP decreased in nearly all G20 countries between 1990 and 2014 (Figure 2.17). As well as structural economic changes, this progress has mainly been due to a general improvement of the energy efficiency of G20 economies rather than an improvement of the carbon intensity of the energy mix. Progress has been varied, but no country has reached the levels consistent with a 66% likelihood of staying below 2°C.[22]

Figure 2.17. **Annual % change in GHG emissions per unit of GDP for selected G20 economies**



Note: Data refer to gross direct emissions excluding emissions or removals from LULUCF. The GDP used to calculate intensities is expressed in USD at 2010 prices and PPPs. The periods covered is 1990-2014 except for: *1990-2013; **1994-2000; #1994-2005; +1990-2013; ++1990-2012.

Source: UNFCCC (2016) and replies to the OECD State of the Environment Questionnaire (accessed through OECD-STAT).

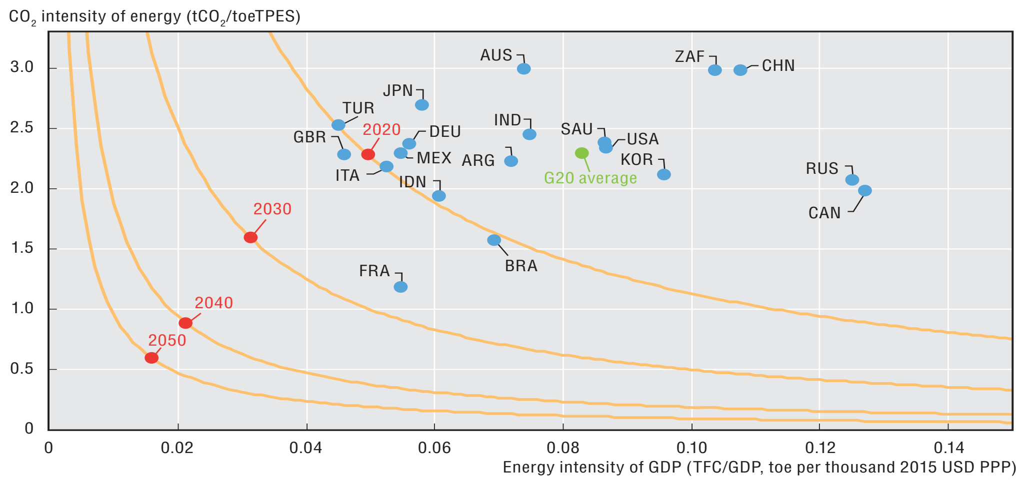
StatLink http://dx.doi.org/10.1787/888933484150

Energy intensity of GDP, CO_2 intensity of energy and energy imports across the G20

Multiplying the CO_2 intensity of energy by the energy intensity of GDP results in the CO_2 intensity of GDP for energy emissions. Figure 2.18 shows lines of constant CO_2 intensity of GDP at levels consistent with the IEA 66% 2°C scenario. Each line is labelled to show the year in which it is projected to be achieved in the IEA scenario,[23] with the data point showing the G20 average projected by the IEA. The 2014 positions of G20 countries are also plotted, highlighting the different starting points and challenges facing different countries as they choose the most appropriate pathways towards the Paris Agreement's goal of well below 2°C. These lines therefore provide a clear direction of travel for country-specific levels of energy intensity and CO_2 intensity of energy. France, for example, has both a relatively low CO_2 intensity of primary energy and energy intensity of GDP, albeit not yet at the levels needed by 2050. Brazil also has a low CO_2 intensity of energy – reflecting the current large share of low-carbon power generation (like France) and the use of bioenergy – but a slightly higher energy intensity of GDP. Further improvements in such economies will require continued investment in low-carbon generation in order to avoid moving backwards, but also priority action in other CO_2-intensive sectors that are harder to decarbonise, such as transport and industry, and continued improvements in energy efficiency.

In contrast, countries like China and South Africa have both a high CO_2 intensity of energy (reflecting coal-powered generation) and a high energy intensity of GDP. Australia also has a high CO_2 intensity but slightly lower energy intensity of GDP, while Canada and Russia have a slightly lower CO_2 intensity, but are more energy-intense economies due to factors including the climate. Of course, countries may have similar levels of energy intensity or CO_2 intensity for very different reasons,[24] and different country outcomes for energy and CO_2 intensity could be consistent with the IEA 66% 2°C scenario. But the direction of travel for all is clear.

Figure 2.18. **The carbon and energy intensity of G20 economies in 2014 and the path to 2050**

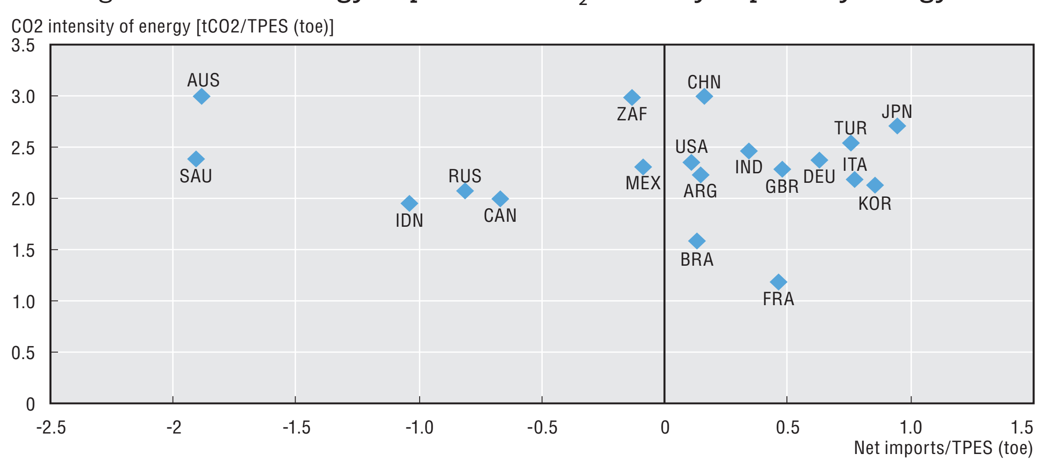


Notes: The average levels for G20 countries (excluding the European Union) refer to 2014 statistical data and the IEA 66% 2°C scenario projections for 2020, 2030, 2040 and 2050. The iso lines show other feasible combinations of CO_2 intensity and energy intensity levels. Calculations assume a constant ratio for total primary energy supply (TPES) to total final consumption (TFC). toe = tonnes of oil equivalent.

Source: Calculations based on the IEA World Indicators and IEA 66% 2°C scenario projections.

StatLink http://dx.doi.org/10.1787/888933484164

Figure 2.19. **Net energy imports and CO_2 intensity of primary energy**



Source: World Bank World Development Indicators (database, accessed February 2017); "World Energy Balances", IEA World Energy Statistics and Balances (database, accessed February 2017).

StatLink http://dx.doi.org/10.1787/888933484176

A further important difference between countries is their position as net importers or exporters of energy (Figure 2.19). There are broadly three groups of countries. For the main net importers of energy, deploying low-carbon energy represents an opportunity in the long run to become self-sufficient in power generation, strengthening their energy security. Many of these countries also have CO_2-intensive primary energy, which means that rapid progress can be made to reduce the CO_2 intensity of electricity generation. For the second group, the main net energy exporters, the low-carbon transition represents a risk in terms of loss of export – and tax – revenues. A final group (or perhaps two sub-groups, comprising net importers and net exporters) – consists of those countries with limited net trade in energy. This may be due to the availability of significant low-carbon energy options (e.g. Brazil), but the group also includes countries with significant fossil fuel resources largely for domestic use, with limited net energy trade relative to total primary energy supply (e.g. Argentina, China, Mexico, South Africa and the United States). The challenges to decarbonisation therefore vary across countries, but are particularly significant for countries that have high CO_2 intensity of energy.

Low-emission pathways for different country groups

As countries develop their low-emission, climate-resilient pathways, an important question is whether these pathways are unique and specific to individual countries or whether groups of countries face similar challenges. Countries that have many characteristics in common could have much to gain by sharing analysis, policy development and experience as they develop their NDCs and pathways. One way of seeing what countries might have in common is to group them by income level – either Advanced (High-Income) Economies or Emerging (Middle-Income) Economies – and whether or not they are energy exporters or importers (Table 2.4).[25]

Table 2.4. **Country groupings**

Group	Advanced Exporters	Advanced Importers	Emerging Exporters	Emerging Importers
Country	Australia* Canada Saudi Arabia	France Germany Italy Japan Korea, Rep. United Kingdom United States	Indonesia Mexico Russia South Africa	Argentina Brazil China India Turkey

Source: OECD calculations. * includes New Zealand following the methodology used in the IEA 66% 2°C scenario.

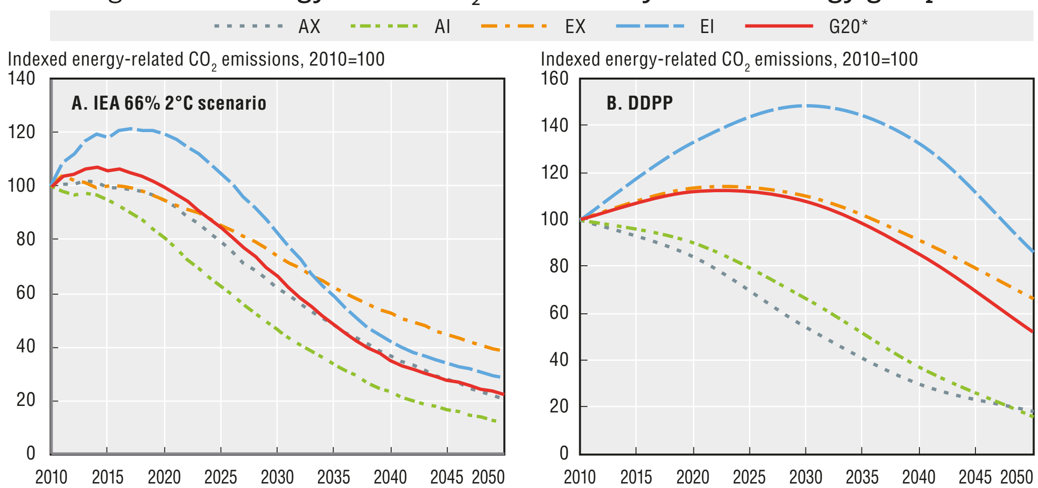
Country characteristics will shape priorities in developing and implementing low-emission, climate-resilient development pathways, as can be seen by examining the outcomes of the Deep Decarbonisation Pathways Project (DDPP). This collaborative project between country modelling teams aimed to identify practical pathways that the G20 countries in which they were based could adopt, taking seriously the GHG emissions reductions required to limit warming to 2°C or less.[26] The DDPP project involved research teams from countries representing 74% of current global CO_2 emissions.[27] Each team developed its own "bottom-up" deep decarbonisation pathway (DDP) based on a sector-by-sector analysis of the feasibility and cost of different mitigation options. Teams were "autonomous in defining their targets, choosing their analytical methods, and incorporating national aspirations for development and economic growth in their scenarios" (DDPP, 2015).

Consequently, the IEA 66% 2°C scenario is more stringent than the DDPP exercise; G20 emissions are projected to fall by almost 80% by 2050 for the IEA 66% 2°C scenario, and about 50% in the DDPP exercise. Nevertheless, both the DDPP results and the IEA 66% 2°C scenario show very different energy-related CO_2 emissions pathways across the income level and energy exporter-importer country groups. Advanced Economies (Exporters and Importers) begin rapid emissions reductions from the outset and are projected to converge at very low levels by 2050. Emissions from Emerging Economies are projected to follow very different tracks.

In the IEA 66% 2°C scenario, Emerging Exporters reduce emissions from 2015 onwards, achieving a reduction of just over 60% by 2050. In the DDPP projections, however, Emerging Exporter emissions increase to 2020 before declining by a smaller 33% by 2050. Emissions from Emerging Importers grow sharply from 2010, peaking around 2017 in the IEA 66% 2°C scenario and in 2030 in the DDPP results, but then fall more rapidly than those from

Emerging Exporters. This group achieves a more than 70% reduction in emissions by 2050 in the 66% 2°C scenario, but a less than 15% reduction in DDPP, reflecting the scale of the initial increase and the differing nature of the two exercises (Figure 2.20).

Figure 2.20. **Energy-related CO_2 emissions by income-energy group**



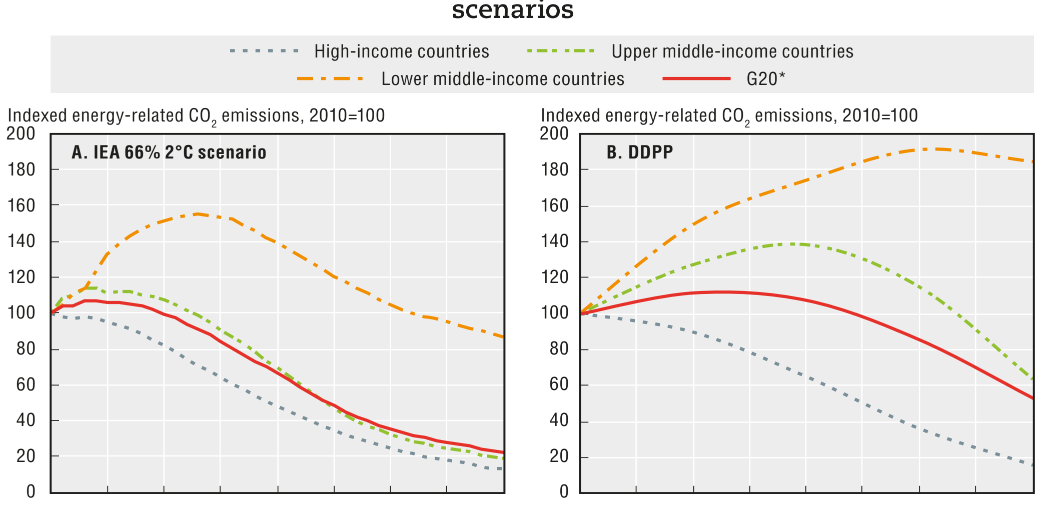
Note: AX: Advanced Exporters. AI: Advanced Importers. EX: Emerging Exporters. EI: Emerging Importers. G20 countries not included in Figure 2.20 (a) are: Argentina, Saudi Arabia, South Africa and Turkey. Australian emissions also include those for New Zealand since they are aggregated in the IEA modelling. Those not included in Figure 2.20 (b) are Argentina, Russia, Saudi Arabia and Turkey. G20* denotes the average across the countries where there is disaggregated data available for each exercise

Source: (a) IEA data underpinning IEA (2017) and OECD calculations. (b) DDPP (2015) and OECD calculations.

StatLink http://dx.doi.org/10.1787/888933484180

Another perspective can be gained by looking at emissions pathways just by income group (Figure 2.21). The joint mitigation-development challenge facing Lower Middle-Income countries is striking. The IEA scenario (LMIC reduction of 13%) would require significantly more stringent mitigation than in the bottom-up DDPP exercise (LMIC increase of 84%). Upper Middle-Income countries are projected to reduce emissions by 80% in the IEA 66% 2°C scenario but only by 36% in the DDPP results.

Figure 2.21. **Emissions pathways by income group in the IEA 66% 2°C and DDPP scenarios**



Note: For G20 country coverage, see note under Figure 2.20.

Source: a) IEA data underpinning IEA (2017) and OECD calculations. (b) DDPP (2015) and OECD calculations.

StatLink http://dx.doi.org/10.1787/888933484191

Other studies have shown potential for emissions reductions to go beyond these levels by 2050 in some emerging economies, though there remain significant challenges in doing so.[28] To keep warming well below 2°C, effective transparency, review and updating processes will clearly be essential, as well as support for climate action in developing countries.

Beyond energy-related emissions, there are clear priorities for countries to preserve existing carbon stocks in forests and other ecosystems by avoiding deforestation and forest degradation and by limiting over-use of nitrogen fertilisers (Prentice, Williams and Friedlingstein, 2015). Enhancing the terrestrial sink for atmospheric CO_2 by afforestation, reforestation and better soil management practices can also make an important contribution (Mackey et al., 2013). Additionally, countries will need to place a greater priority on building resilience and adaptive capacity.

Climate-resilient pathways reflecting regional climate change

Even if global action to reduce GHG emissions increases enough to meet the Paris Agreement goal of well below 2°C, the impacts of climate change will still increase far beyond today's level. Examining the projected impacts on a regional basis can help countries to develop climate-resilient pathways.

Projected regional climate changes

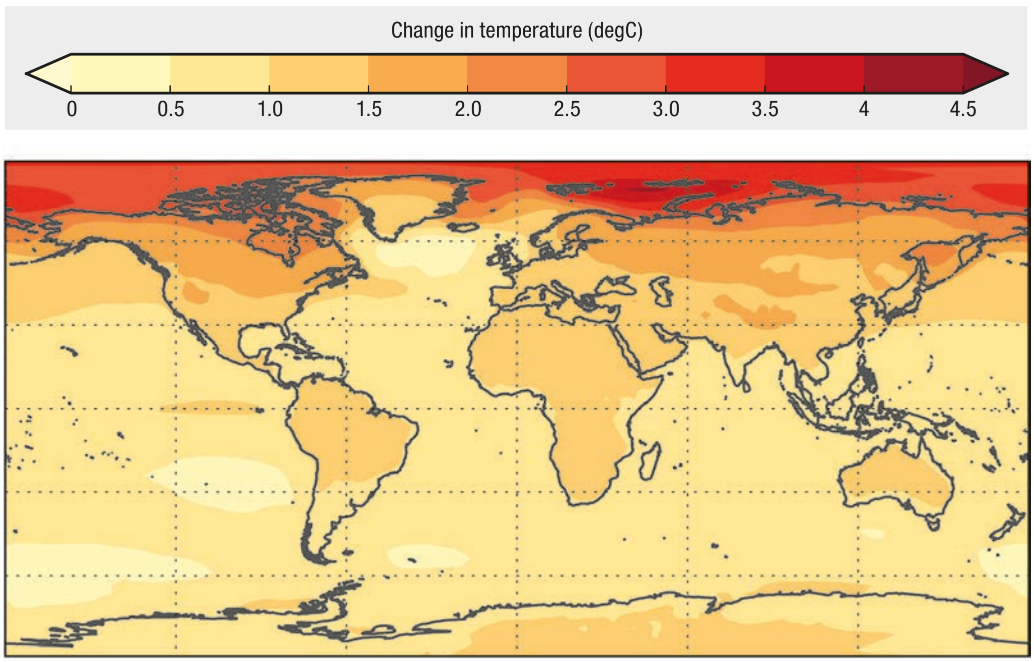
This section presents results for two different RCP scenarios simulated by a number of the climate models that informed the IPCC's Fifth Assessment Report (IPCC, 2013). The first is the RCP2.6 scenario. The second is the RCP4.5 scenario, which has mean end-of-century warming across models of 2.4°C. Both therefore have end of century warming relative to the pre-industrial time period below the level associated with the emissions pathways implied by countries' Nationally Determined Contributions (NDCs) to GHG emissions reduction post-2020, as described below. The RCP4.5 scenario is, however, broadly in line with the NDCs earlier in the century.

The following figures show maps of projected climate changes between the recent past (1986-2005) and mid-century (2046-65) for these two RCPs. The mean average change for different regions across the available climate models is shown, but individual models may give results that differ in terms of the magnitude of changes and details of the spatial patterns of change.

Temperature

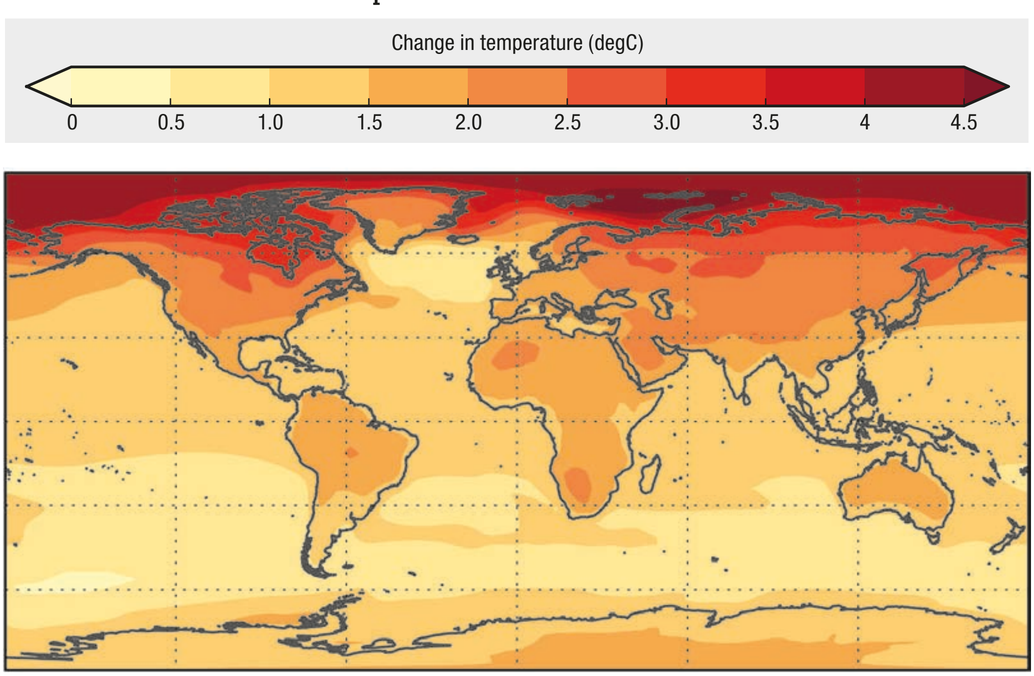
The regional pattern of projected temperature changes to mid-century (2046-65) is similar for both RCP2.6 (Figure 2.22) and RCP4.5 (Figure 2.23), but with greater changes in RCP4.5. For RCP2.6, projected regional warming values exceeding 2.5°C are confined largely to the Arctic Ocean, while in RCP4.5 projected warming exceeds 2.5°C over most of Alaska and much of Canada and Russia. Despite the greater warming in these areas, long-term warming may be more noticeable in tropical countries, such as Indonesia, where the variability in temperatures from year to year is lower. For both scenarios, model-average warming is less in the Southern Hemisphere than in the Northern Hemisphere, with warming across the Southern Hemisphere being less than 2.5°C for RCP4.5 and less than 1.5°C for RCP2.6.

Figure 2.22. **Projected absolute change in annual mean surface temperature for RCP 2.6 for the period 2046-65 relative to 1986-2005**



Note: Maps show average changes across available global climate model simulations.
Source: MOHC analysis.

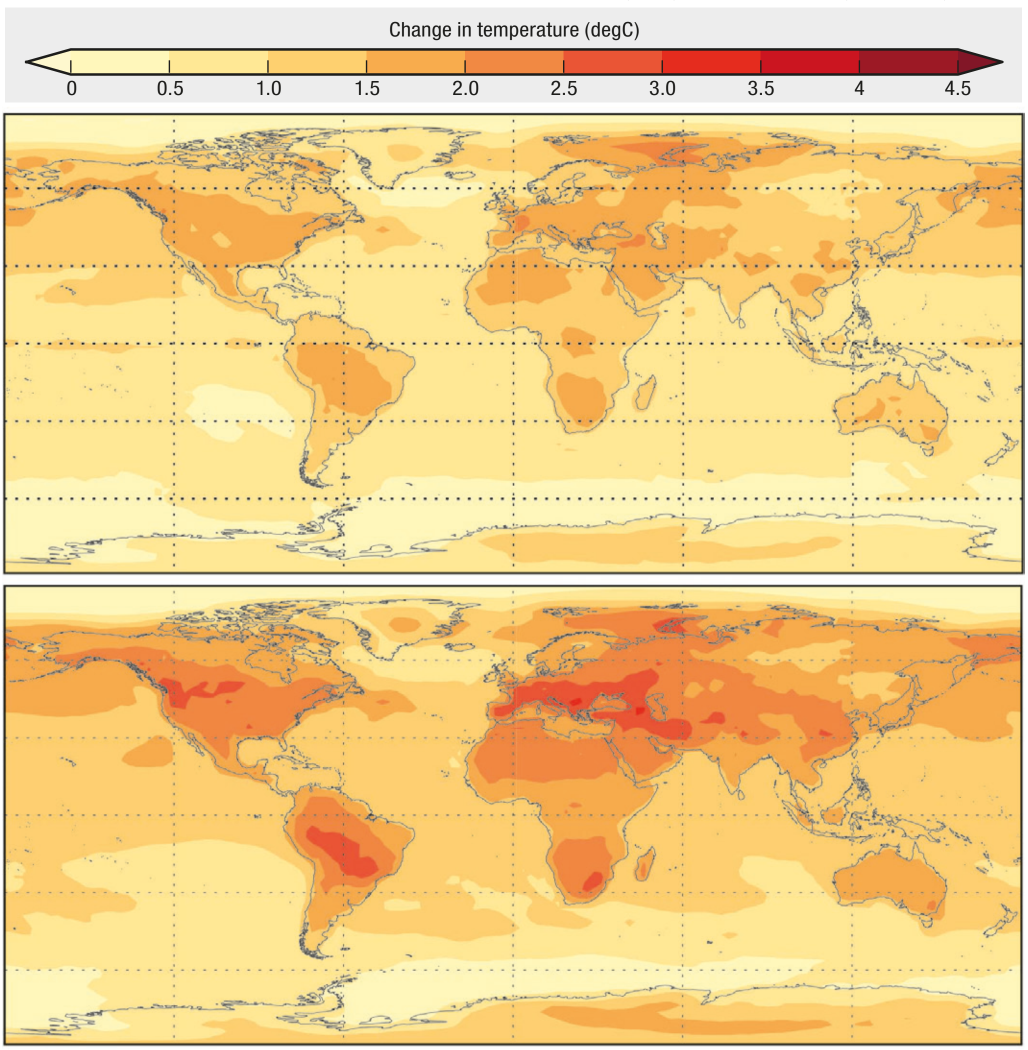
Figure 2.23. **Projected absolute change in annual mean surface temperature for RCP 4.5 for the period 2046-65 relative to 1986-2005**



Note: Maps show average changes across available global climate model simulations.
Source: MOHC analysis.

The regional pattern of changes in extreme temperatures is quite different from that for changes in annual mean temperature. For example, those regions expected to experience the greatest increases in the temperatures of very hot days differ from those expected to see the largest increases in annual mean temperatures (Figure 2.24). For both scenarios, the maximum temperature during a year is projected to increase most over parts of continental Europe, southwest Asia, North America and inland regions of South America, such as western Brazil. As for annual mean temperatures, the increase in maximum temperature during a year is projected to be greater for RCP4.5 than for RCP2.6. For example, over parts of southeast Europe the model-average increase in maximum temperatures during a year is more than 3.0°C for RCP4.5, whereas it is less than 2.5°C under RCP2.6.

Figure 2.24. **Projected changes in the maximum temperature during a year between 1986-2005 and 2046-65 for RCP2.6 (top) and RCP4.5 (bottom)**



Note: Maps show average changes across available global climate model simulations.
Source: MOHC analysis.

Precipitation

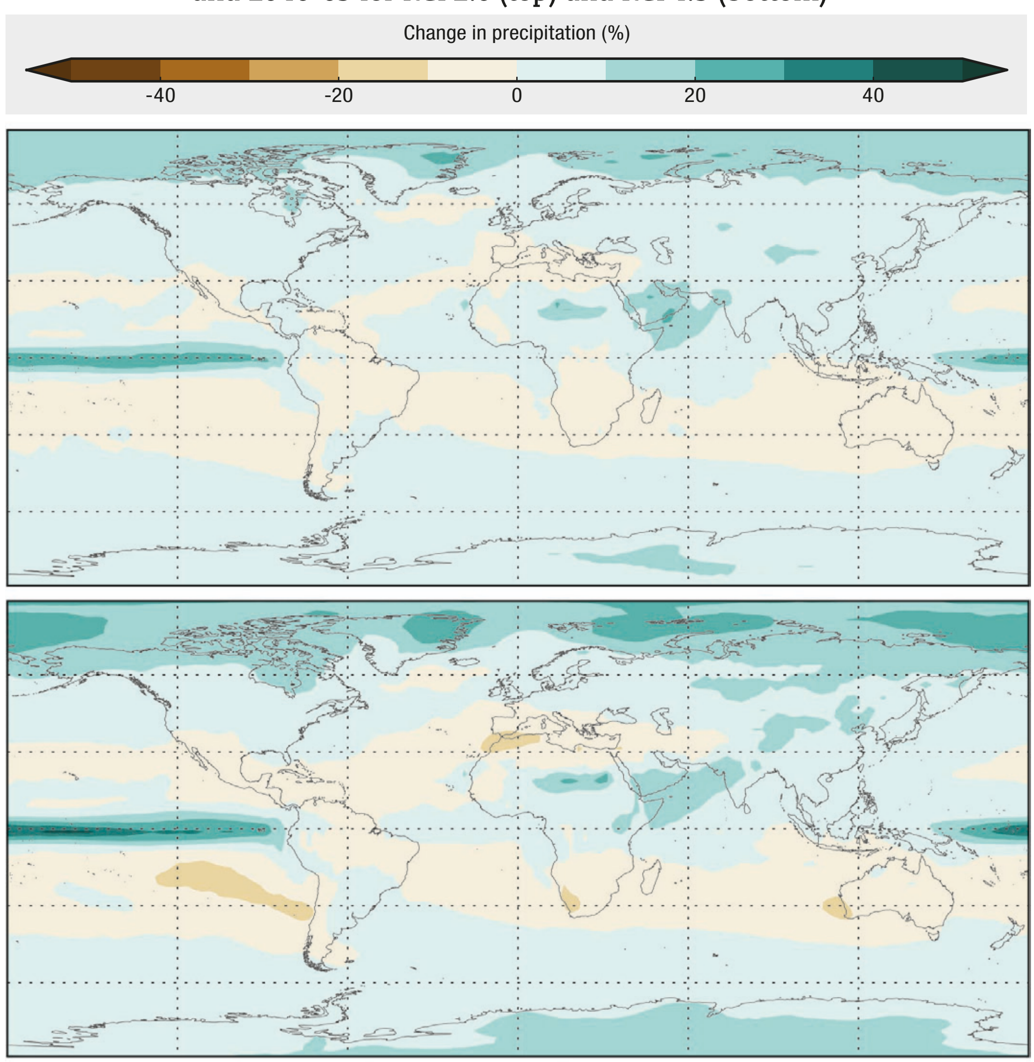
In both RCP2.6 and RCP4.5, global average annual mean precipitation is likely to increase by 2-3% on average between 1986-2005 and 2046-65 (Table 2.5). Projections are highly uncertain on the country scale, however. For most of the G20 countries, some simulations show increases in precipitation while others show decreases. Nonetheless, both scenarios show the same coherent pattern of precipitation increasing in some areas and decreasing in others, particularly northern Africa, southern Europe, Central America, northern South America, southern Africa and Australia (Figure 2.25). For RCP4.5, the greatest model-average precipitation decreases for the G20 countries – of more than 6% – are projected for some of the Mediterranean countries. The same countries are projected to experience more modest precipitation decreases for RCP2.6 of around 2% or 3%. For RCP4.5, the greatest model-average precipitation increases projected for the G20 countries – of more than 7% – are for Canada and Russia.

Table 2.5. **Projected percentage changes in global average annual mean precipitation and maximum daily precipitation total during a year between 1986-2005 and 2046-65 for RCP2.6 and RCP4.5**

	Change in annual mean precipitation		Change in annual maximum daily precipitation total	
Scenario	**Mean**	**Likely range**	**Mean**	**Likely range**
RCP2.6	+2.2	+0.5 – +3.8	+5.7	+2.3 - +9.1
RCP4.5	+2.6	+1.0 – +4.1	+6.8	+1.8 - +11.8

Source: MOHC analysis.

Figure 2.25. **Projected changes in annual mean precipitation between 1986-2005 and 2046-65 for RCP2.6 (top) and RCP4.5 (bottom)**



Note: Maps show average changes across available global climate model simulations.
Source: MOHC analysis.

In all G20 countries, global average extreme precipitation is expected to increase more than global average annual mean precipitation. Global average maximum daily precipitation is likely to increase by 6% on average for RCP2.6 and 7% for RCP4.5.

Climate impacts and the SDGs

The choice of development pathway will have a major influence on how climate change affects poverty levels (Hallegatte et al., 2016). In a scenario where economic growth is higher, inequality is lower and there is better provision of basic services, climate change is estimated to increase the number of people in extreme poverty in 2030 by 3 to 16 million people. By contrast, under a more pessimistic scenario, extreme poverty could increase by 35-122 million people because of climate impacts on agriculture, health, labour productivity and the incidence of natural disasters (Hallegatte et al., 2016).

Agriculture will be affected by the changes in precipitation patterns and ecosystem services that are projected to occur with climate change. IPCC (2014b) reported that negative impacts of climate change on yields of crops such as wheat and maize have been more common than positive impacts. Crop yields are projected to increase by 2050, but by less than would otherwise be the case (Ignaciuk and Mason-D'Croz, 2014). Under a very high emissions scenario (IPCC scenario RCP 8.5), climate change could increase the prices of major grains by 5-30%, leading to increases in the proportion of people suffering from malnutrition in South- and Southeast Asia, Middle East and North Africa and Sub-Saharan Africa. Without adaptation, aggregate production losses are expected for wheat, rice and maize for 2°C of local warming (Challinor et al., 2014). This applies to both temperate and tropical regions and increases over the century.

While health impacts are modest at this stage, they are projected to be a major source of harm from climate change (Smith et al., 2014). Increases in heat-related mortality are projected to outweigh the decline in cold-related mortality. The dangers of extreme heat were illustrated by the prolonged 2003 heatwave in France, which is estimated to have led to almost 20,000 excess deaths (EM-DAT, n.d.). The 2015 heat wave in India led to 2 248 deaths (EM-DAT, n.d.). In the absence of adaptation, climate change could lead to 250,000 excess deaths per year by 2050 (WHO, 2014). Climate change increases the risk of illness from food- and water-borne disease as well as the spread of vector-borne diseases, with as many as 200 million more people being at risk in 2050 (Béguin et al., 2011).

Labour productivity, particularly in warm countries with high proportions of outdoor labourers, will be reduced by 3-5% per degree for outdoor activities. The overall decline in labour productivity will be 1% in most OECD countries (OECD, 2015b). In non-OECD countries, average labour productivity is estimated to have declined by 10% during peak temperature months over the past decades, and could decline by 20% during peak months by 2050 (Dunne et al., 2013). Impacts on labour productivity are likely to disproportionately affect the poor, especially women, who tend to work in climate-sensitive sectors and have fewer resources for adaptation (Hallegatte et al., 2016). Asia and Africa will suffer the most significant effects.

Climate change will exacerbate water-related risks. Increasing demand and decreasing supply will result in water shortages. Rising sea levels will cause flooding, as will changing patterns of rainfall and extreme rainfall episodes. Water quality will also suffer. Some 3.9 billion people are projected to live in areas of severe water scarcity by 2050 (OECD, 2012). In coastal cities, annual losses from flooding could rise from USD 6 billion in 2005 to USD 1 trillion per year by 2050, if flood defences are not improved (Hallegatte et al., 2013) (Figure 2.26). The countries at greatest risk from coastal city flooding span developed and developing countries, including the United States and China.[29]

Developing climate-resilient pathways

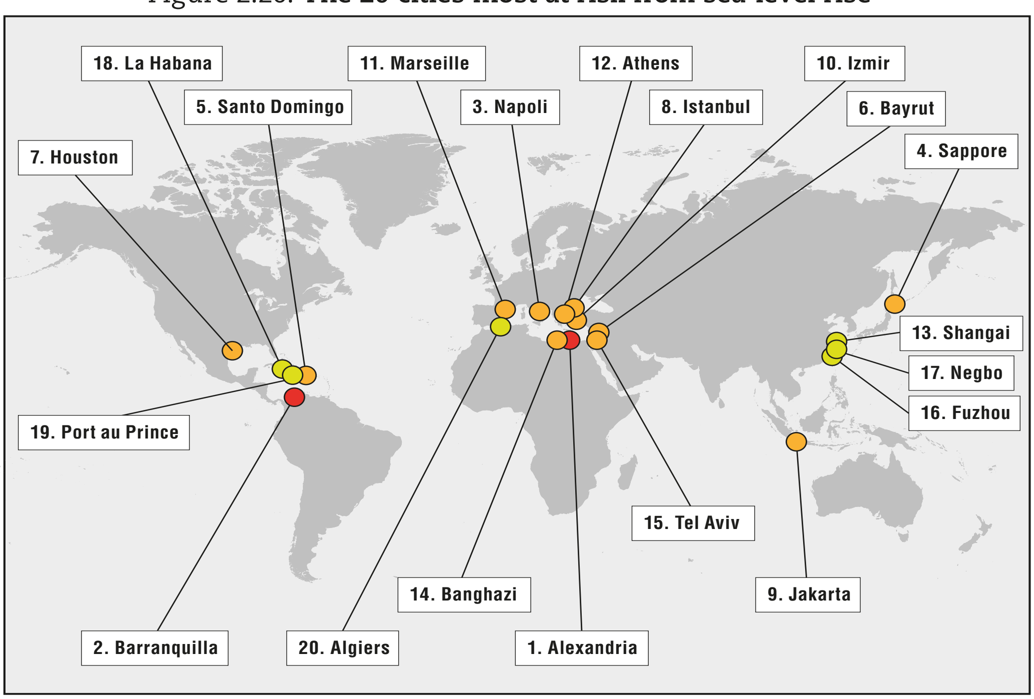
Countries' vulnerabilities to climate change are shaped by development choices, socio-economic trends and climate effects that cross borders and will demand flexible, forward-looking approaches to decision-making.

As with mitigation action, a primary determinant of countries' ability to adapt is their GDP per capita. Richer countries will be better able to adapt to the impacts of climate change than those with lower GDP per capita; they have more resources to invest in adaptation and recovery. This can be seen in the correlation between GDP per capita and standards of protection against flooding (Hallegatte et al., 2017). There are also indirect effects: richer countries tend to have higher quality institutions, leading to more rigorous planning and better implementation of policies. More developed financial markets mean that households and businesses are better able to manage the financial consequences of extreme events.

How much rainfall countries receive – and how much this is expected to change – also affects countries' ability to adapt. Climate change is expected to reduce precipitation in regions that are already severely water-stressed. Moreover, the loss of Asian and Andean glaciers will place further stress on freshwater availability in countries in South Asia and South America. The need to reconcile supply and demand will shape the range of feasible development paths, constrain some adaptation options (such as irrigation) and increase the urgency of developing an efficient policy response.

The variability of precipitation is also a key factor for adaptation. Monthly variability in water runoff, GDP per capita and investments in water security are interconnected (Sadoff et al., 2015). River basins in high-income countries tend to have less variable runoff and higher investment in water security. In contrast, river basins in low-income countries tend to feature variable runoff and low investment in water security. As climate change makes precipitation less predictable, it will be vital to enhance investment in water security to address these fluctuations.

Figure 2.26. **The 20 cities most at risk from sea-level rise**



Note: Cities where expected annual average losses increase most (in relative terms in 2050 compared with 2005) in the case of "optimistic" sea-level risk, where defence standards are held constant.

Source: Hallegatte et al., 2013. Reprinted by permission from Macmillan Publishers Ltd: Nature Climate Change 3, 802–806 copyright (2013).

Political choices will also affect countries' vulnerabilities to climate change. Countries at similar levels of economic development vary widely in the levels of climate risks that they are willing to accept: New York is protected against a 1:100 year flood while Amsterdam is protected to a standard of 1:10 000. The development path that each country pursues will affect the cost and feasibility of achieving different levels of risk reduction: for example, development in low-lying coastal areas may subsequently necessitate large investments in coastal protection, or relocation to higher ground.

Countries can reduce their vulnerability to the effects of climate change by pursuing inclusive development. Poverty, marginalisation and inequality constrain people's ability to adapt to a changing climate. The poor tend to live in higher-risk areas and have less access to public services (Hallegatte et al., 2017). Moreover, the poor and marginalised have few resources with which to cushion the impact of climate shocks, with the result that such shocks can cause long-term harm, and even transform transient poverty into chronic poverty (Olsson et al., 2014). Ensuring that development is inclusive can avoid a vicious cycle between climate change and poverty.

Box 2.6. **Adaptation pathways: the Delta programme**

The Delta programme is designed to protect the Netherlands against the risk of flooding and ensure access to fresh water. An approach called "adaptation pathways" has been used to identify different sets of policy measures that could meet these objectives, given uncertainties about how the climate, the economy and society will evolve. Multiple model runs are used to project the range of potential variables over time. Based on this process, the analysis identifies tipping points where additional or different actions may be required to ensure that the objectives are met under some scenarios.

At each tipping point, there is a range of potential options – a "decision tree". Depending on the one chosen, the options available further down the track may differ. The combinations of available options offer many different pathways, which are all projected to meet the same performance criteria. These alternative pathways can then be compared using a range of qualitative and quantitative criteria. Once a pathway has been chosen, a monitoring system is established to track changes in relevant variables and change course if needed. The involvement of relevant stakeholders is essential to ensure that the right dimensions of each decision are taken into account and that there is a shared understanding of the likely consequences of different options.

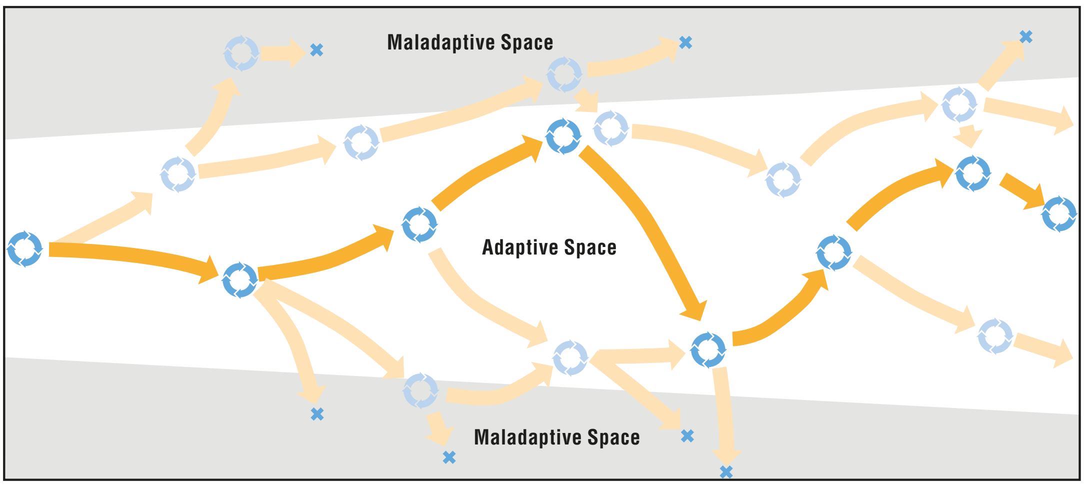
This approach directly addresses the challenge of long-term planning in an environment of pervasive uncertainty. One of its main benefits is that it ensures that the actions taken today are consistent with the longer-term objectives. It also supports a flexible response, by identifying how options will open up or preclude certain actions in the future.

Source : Haasnoot et al., 2013

Since countries' circumstances differ, so will their appropriate adaptation responses. The concept of "adaptation pathways" has been pioneered to ensure that large infrastructure projects are able to respond to changing circumstances over the course of their useful life (Box 2.6). The underlying principle is to identify the range of potential outcomes that could materialise and then work backwards to identify the range of measures that would be needed to address those outcomes. The adaptation pathway provides a formalised way of identifying sequencing, path dependencies and the points where decisions need to be made (Haasnoot et al., 2013).

At the national level, the concept of adaptation pathways provides a model for viewing adaptation as a process for adjusting to changing circumstances over time. There is a succession of decision-points over time, each of which then determines the future range of opportunities that are open to decision-makers (Wise et al., 2014) (Figure 2.28). In practice, however, the process is less straightforward, because of the need to define what constitutes successful adaptation, difficulty in measuring the current state of progress and competing views about the appropriate responses to a changing climate. Nonetheless, the underlying approach of cycles of implementing actions, learning and adjusting course provides a useful description of the adaptation process.

Figure 2.28. **Iterative decision cycles**



Source: Wise et al., 2014

National Adaptation Plans (NAPs) provide an important tool for communicating priorities and putting in place the key elements required to support adaptation. Adaptation will be the product of a multitude of decisions, ranging from farmers' choices of crops to urban planning, undertaken by a wide range of actors facing different sets of opportunities and constraints. Climate change will be just one of many factors that could influence how people respond to change. This means that it is neither possible nor desirable for every adaptation action to be dictated in a top-down manner. Instead, adaptation strategies such as NAPs should aim to strengthen the capacity of relevant decision makers to account for climate change. An important element of this is to influence investment decisions by demonstrating political commitment and setting the strategic direction for resilience at the national level.

The basis for effective adaptation is having access to suitable data in a usable form, combined with the tools to interpret the implications of climate change for the relevant decisions. These data should be regularly updated and reliable, which may require improvements in countries' statistical capacity.[30] Providing information is necessary, but not sufficient, to guarantee informed decision-making. The governance arrangements that determine how decisions are made may themselves need to be adapted to make them responsive to the effects of climate change. Action by governments may be required if inertia in existing governance systems means that they are no longer fit for purpose in a changing climate (Wise et al., 2014). For example, adopting a risk-based approach in the water sector requires involving a broader set of stakeholders, obtaining different information and changing the objective of the decision from meeting certain technical standards to achieving acceptable levels of risks. Regulatory reforms may be required to enable these changes to occur.

At the project level, there are clear metrics to assess progress and inform decision-making as part of an adaptation pathway. In contrast, the concept of national pathways cannot be readily quantified, because of the nature and diversity of actions that they include. For this reason, it is vital to use both quantitative and qualitative information to assess progress (OECD, 2015d). Relevant tools for doing so include national risk assessments, indicator sets and in-depth evaluations of large projects. This process is likely to be most effective when it is integrated into existing processes for monitoring and evaluation, rather than being implemented as a standalone system.

OECD analysis of infrastructure resilience shows that action is required across four policy areas (Vallejo and Mullan, 2017):

- supporting decision-making by providing tools and information;
- screening and factoring climate risks into public investments;
- enabling infrastructure resilience through policy and regulation;
- encouraging the disclosure of climate risks.

Spatial planning is another critical area for climate change adaptation, given that it can shape the location and design of new physical assets. There are two main challenges for spatial planning: ensuring that development is only permitted in lower-risk areas, and that the spatial plans are enforced. Unplanned urbanisation is a common feature of rapidly developing economies, with informal settlements being established in areas that are too risky for formal development, such as river banks and hillsides. As a consequence, the people with the fewest resources for managing climate risks are located in some of the highest risk areas.

Well-planned urbanisation can reduce the disparities in exposure between high-and low-income groups. Where the following conditions hold, the differences in exposure between income groups remain low (Revi et al., 2014):

- buildings meet construction standards;
- development is only permitted in lower-risk areas;
- infrastructure and basic services are provided to all.

Managing the effects of climate change on ecosystems will be an essential element of climate change adaptation pathways. Ecosystems are already under severe pressure as a result of deforestation, water pollution, over-fishing and other causes. The OECD Environmental Outlook to 2050 projected that biodiversity would decline in all world regions under business-as-usual policies. Climate change will place a further burden on ecosystems, as the rate of change exceeds plants and animals' abilities to adapt. There is already evidence of plants and animals having moved to new areas and changed their seasonal activities in response to climate change (Settele et al., 2014). Several policy options can be used to protect ecosystems from the impacts of climate change. The first priority is to strengthen efforts to alleviate the non-climate pressures on ecosystems. A crucial element of this is to mainstream biodiversity – and ecosystems more generally – into national and sectoral planning (OECD, forthcoming). Beyond this, several measures can be taken to lessen the effects of climate change on ecosystems (Settele et al., 2014):

- Adaptive landscape management: Ensure that landscape management strengthens resilience and capacity to adapt to change. Ensure that institutional arrangements, regulations and policies are designed with the expectation that ecosystems will change.
- Supporting biodiversity migration: Create and maintain migration "corridors" to support the process of ecosystem adaptation. In some cases, it may be necessary to move species to a new location.
- Off-site conservation: Preserve diversity through measures such as seed banks and breeding programmes. Several issues need to be resolved to ensure the successful reintroduction of preserved resources into the wild.

Ecosystem-based approaches can play an essential role in building resilience to the effects of climate change. In some cases, they can be cheaper and more flexible than hard infrastructure, and generate benefits beyond adaptation. For example, wetland protection or restoration can reduce flood risk, while also storing carbon and supporting biodiversity. Economic instruments such as Payments for Ecosystem Services should be used to enhance the provision of ecosystem services (OECD, 2010).

Linking adaptation and mitigation

Mitigation supports adaptation by delaying and reducing the scale of climate impacts. At a global level, this reduces the scale of the adaptation challenge. Mitigation also reduces the risk of encountering climate extremes that cannot be adapted to. In principle, credible commitments to a low-emission trajectory would reduce the total need for investments in climate change adaptation (OECD, 2015c). However, in practice this is not so simple (Wilbanks, 2005):

- *Dealing with uncertainty:* Adaptation decisions need to be made today based on expectations about the extent of future climate change. In terms of mitigation efforts, the question is then about expectations as well as outcomes, including the credibility of emissions reduction commitments.
- *Different time horizons:* Within the 2050 planning horizon, the differences are relatively modest between emissions trajectories but will become more severe over time. Implications for adaptation decisions will vary depending on the degree of lock-in.
- *Diverse actors:* Much adaptation is expected to be local and autonomous. Mitigation is focused on the main emitting sectors, while adaptation will take place in those that are most sensitive to the effects of climate change.
- *Distributional issues:* The benefits of adaptation are primarily local and near-term, while the primary benefits of mitigation are long-term and global.

At the level of specific adaptation measures, there are synergies and trade-offs. For example, half of the new coal power plants in China are being built in areas of high water stress (Luo et al., 2013). Replacing coal with wind or solar power would yield both mitigation and adaptation benefits. However, not all good things go together. Between mitigation and adaptation actions there are tensions as well as mutual benefits (Table 2.6). Inappropriate biofuels production, for example, could exacerbate problems with food security.

Table 2.6. **Potential synergies and trade-offs between adaptation and mitigation measures**

	Positive for mitigation	Potential trade-off with mitigation
Positive for adaptation	**Reduced deforestation:** Sequesters carbon and provides ecosystem services.	**Desalination:** Addresses water shortage but is energy-intensive.
	Agricultural practices (e.g. no till): Sequesters carbon and can boost farmers' incomes.	**Increased irrigation:** Helps farmers manage variable precipitation but can be energy-intensive.
	Wetland restoration: Carbon sequestration and reduced flood risk.	**Air conditioning:** Reduces the impact of high temperatures on health, but is energy-intensive.
	Renewable energy (wind, solar PV): Lower water use than thermal generation.	**Construction of hard defences:** Reduces the risk of extreme events, but GHGs are embodied in the construction.
Potential trade-off with adaptation	**Inappropriate expansion of biofuels:** Could exacerbate food price shocks if biofuels displace crops.	
	Hydropower: Could increase the complexity of managing water resources.	

To develop and implement effective climate policy, it is vital to ensure coherence between adaptation and mitigation policies.[31] At the level of individual projects, this means ensuring that the appraisal process takes into account the full range of relevant costs and benefits, including impacts on carbon emissions and on resources relevant for adaptation, such as water. Some projects will inevitably involve trade-offs; it is important that they are acknowledged to ensure that any negative impacts on mitigation or adaptation are justified.

Getting from here to there

Climate change is a global externality because GHG emissions in one country cause damages in other countries that are not currently adequately factored into decisions (Stern, 2007). Economic theory also tells us that a global public good such as a stable climate can only be delivered through effective collective action at the international level: each country is asked to incur costs to reduce emissions, but the benefits of these efforts are shared globally.[32] The costs and benefits of climate action are distributed unevenly across countries and over time, and are to some degree still uncertain. Mitigation costs fall early on, while the major benefits in terms of avoided impacts would be seen later in the century.[33] This provides incentives for countries to free-ride on the actions of others, either now or in terms of the damages that will face future generations.[34] Developed countries have been responsible for most of the cumulative CO_2 emissions so far, but developing countries will make up most future emissions. In the meantime, technological advances have massively reduced the costs of key renewable technologies.

This final section addresses the key question of how countries get to where they need to be. It discusses the NDCs, which are not aligned with a cost-effective path towards the Paris Agreement goal of well below 2°C. Finally, it underlines the fundamental importance of the Paris Agreement in efforts to build the trust and transparency needed to go beyond current levels of mitigation action.

The Nationally Determined Contributions

As part of the process of creating a new international climate agreement under the UNFCCC, each party submitted its proposed national climate action plan, known as its intended "nationally determined contribution" or NDC (Box 2.7). The Paris Agreement requires that parties "prepare, communicate and maintain" their NDCs.[35] In parallel, developed countries reaffirmed their commitment to support developing countries by mobilising USD 100 billion a year by 2020 from public and private sources. Emphasis was also placed on a just transition for workers, through the creation of good quality jobs in line with national development priorities.

The NDCs set out the post-2020 climate actions parties intend to take: for example, decarbonising energy supply through shifts to renewable energy, energy efficiency improvements, better land management, urban planning and low-carbon transport at the city level (see Annex 2.A1 for details of the G20 countries' NDCs). Taken together, the NDCs are a progression beyond current policies but are not enough to keep global warming below 2°C; they are more in line with emissions scenarios that keep the temperature rise to below 3°C in 2100 (UNEP, 2015).[36] Analysis of the NDCs suggests that emissions will continue rising to 2030 (UNFCCC, 2015b). Additionally, the NDCs imply significant variations in future carbon prices across countries, suggesting substantial potential gains to emissions trading.[37] To drive investment in low-emission technologies, the NDCs need to be both credible and backed by good domestic policy design, which includes flexibility to adjust (see Chapter 6) (Nemet et al., 2017).

In adopting a dynamic, hybrid approach – part bottom up, part top down monitoring and review of the adequacy of country efforts against global targets – parties to the UNFCCC have secured broad participation in international mitigation efforts, but at the (hopefully) short-term cost of environmental effectiveness and economic efficiency. The plateau in energy-related CO_2 emissions over the last three years is a positive sign, though it is still too early to claim that we are at a peak of total global emissions, let alone the subsequent rapid reductions required to keep warming "well below 2°C" (IEA, 2017).

Box 2.7. **G20 countries' NDCs vary widely**

The G20 countries' pledges differ in terms of the kind of emissions reduction they specify, the conditions they set, their target dates and the GHGs they cover.

An absolute emissions reduction relative to a base year. The G20 European Union countries (France, Germany, Italy and the United Kingdom) have opted for 1990 as the base year, along with the Russian Federation. This reflects the type of target and base year agreed under the Kyoto Protocol. Australia, Brazil, Canada and the United States have identified their target relative to their GHG emission levels in 2005.

A reduction in the emissions intensity of the economy relative to a base year. India, for instance, has pledged a 33-35% reduction of the emission intensity of its GDP while China aims for a 60-65% reduction. Both countries use 2005 emissions intensity of the economy as their baseline.

Emissions reduction relative to a business-as-usual scenario (without further climate policies): This is the case for the NDCs of Indonesia, Korea, Mexico, Saudi Arabia, and Turkey.

A specified emissions trajectory: South Africa has pledged a "peak, plateau and decline" of emissions, describing a path over the next 20 years. Argentina has placed an absolute cap on its 2030 emissions.

Conditionality: Several countries have set conditions for the achievement of some – or all – of their targets. These include the provision of financial, technical or capacity-building support from developed countries (e.g. for Argentina, India, Indonesia, Mexico, Saudi Arabia), the degree of the implementation of the Paris Agreement by developed countries (for South Africa). Argentina, Indonesia and Mexico have both unconditional and conditional targets, the latter requiring support from developed countries.

Target date: Most G20 countries have set 2030 as their target date. The United States and Brazil chose 2025; South Africa has target periods of 5 years going from 2020 to post-2035.

Coverage: Most G20 pledges cover the six Kyoto Protocol GHGs[38] as well as the economic sectors outlined by the IPCC.[39] Australia, Canada, the European Union, Japan, the Russian Federation, Turkey and the United States have also included nitrogen trifluoride (NF_3), added on the list of GHGs under Kyoto Phase II, in the target gases. Mexico also focuses on black carbon, while Indonesia includes only CO_2, CH_4 and N_2O.

Building on the Paris Agreement

Early efforts to forge an effective international response to climate change resulted in the 1992 UN Framework Convention on Climate Change (UNFCCC), the start of an open-ended negotiating process that led to the Paris Agreement in December 2015. The Paris Agreement aims to strengthen the international response to climate change by building on the bottom-up approach initiated at the Copenhagen COP15 meeting in 2009.[40] It also adds "an enhanced transparency framework", to help track progress of individual parties on mitigation and adaptation action as well as on support for developing countries (finance, technology and capacity-building). This framework is vital, given the evidence that trust and reciprocity are important for successful management of natural resources (Ostrom, 1990).[41] The framework will support several processes and milestones for collective stocktaking and oversight of progress made on long-term goals.[42]

An immediate priority within the UNFCCC process is to put the Paris Agreement into operation by reaching agreement on the rules and modalities for several key provisions, including those on monitoring, reporting, verification and assessing collective progress according to the timeline established at COP21.[43] Headway here is essential to build the trust needed to increase the stringency of action over time. This is the current focus of the OECD-IEA Climate Change Experts Group.

The Paris Agreement architecture has yet to demonstrate that it can catalyse the urgent and stringent mitigation action and support needed to meet the Agreement's goals. Parties must now implement their emissions limitation and reduction pledges to 2020 and their aims beyond 2020. The aggregate mitigation effect of the NDCs is inadequate, however, and countries need to scale up their efforts. Developed country support for climate action will be important, not just for mitigation but also to improve the resilience and adaptive capacity of countries facing the greatest climate challenges.

At COP21, parties were invited to communicate by 2020 the long-term low-emission development strategies they will follow up to 2050. Six countries have done so; it is crucial that more follow suit. This is an important mechanism for helping countries to align short-term actions with long-term goals and to minimise the risks of either emissions lock-in or stranded assets. One important initiative to support this and to build broader engagement and action is the 2050 Pathways Platform launched at COP22 in Marrakech, Morocco (Box 2.8).

Success will not solely depend on action at central government level. The UNFCCC process has over recent years deliberately and increasingly created mechanisms of engagement with and commitments from non-state actors, most notably under the Lima-Paris Action Agenda in the run-up to COP21, on issues as diverse as cities, private finance and forests.

Box 2.8. **The 2050 Pathways Platform**

The 2050 Pathways Platform was launched at the High-Level Event of COP22 in Marrakech. Membership is growing quickly: 22 countries, 15 cities, 17 regions and states, and 192 companies have already joined.

Short-term GHG emissions reduction targets and actions such as the NDCs need to be set and implemented consistently with the long-term global goal. Developing pathways from now until 2050 can help in envisaging the structural changes necessary to achieve net-zero GHG emissions, as opposed to incremental changes. The platform helps countries design and implement long-term deep decarbonisation strategies that will limit the average global temperature increase to well below 2°C. It does so by sharing resources (including finance and capacity building), experience and best practices. It also builds a broader constellation of cities, states, companies and investors engaged in long-term low-emission planning of their own, and in support of the national strategies. It is envisaged as a space for collective problem-solving.

Pathways to 2050 need to be socio-economic development pathways, not just GHG emission reduction pathways; adaptation is an important component. Developing 2050 pathways can help to capture the synergies between socio-economic development and climate change mitigation, for example by aligning climate action with objectives on health, innovation and food security. They are also a risk-management tool: they can avoid carbon lock-in, and therefore reduce the risk of stranded assets, by putting short-term climate actions in the context of the long-term climate transition.

Pathways to 2050 need to be co-designed – and ultimately owned – by all relevant stakeholders: not just politicians and policy-makers, but also businesses, unions, NGOs and others. They also need to be informed by the best expert knowledge and evidence. The Platform aims to leverage a range of international processes to provide: technical analysis and support; sharing lessons learned and best practices; and multi-stakeholder/cross-jurisdictional dialogues.

Source: 2050 Pathways Platform team.

Notes

1. High levels of CO_2, associated with enhanced warming, also lead to increased acidification of the ocean and impacts on corals and a wide range of marine ecosystems.
2. Yet 13 percent of the world's population lived below the international poverty line of US$1.90 per day in 2012, see World Bank (2016).
3. CO_2 contributed about 76% of global warming in 2010 (IPCC, 2013).
4. Taken here as the 1850-1900 average.
5. Scientists have more confidence in their understanding and projections of global surface temperature than of precipitation, since the latter depend on the dynamics of the atmosphere, not just on energy-balance considerations. There is also have greater confidence in projections of global or continental scale changes than at regional or local scale. Global Climate Models (GCMs) are the basis of much of the information on future climate changes presented in the IPCC's assessment reports. See Taylor, Stouffer and Meehl (2012) on the Coupled Model Intercomparison Project Phase 5 (CMIP5), which was used in IPCC AR5 (2013). Such exercises help to determine the strengths and weaknesses of the various GCMs and inform their future development.
6. The Representative Concentration Pathways (RCPs) used in the most recent IPCC AR5 report span a wide range of possible future emissions scenarios. They are used to illustrate a range of possible climate futures to 2100 (Moss et al., 2010) by specifying different concentrations of GHGs and other atmospheric constituents (such as aerosols). These scenarios are named RCP2.6, RCP4.5, RCP6.0 and RCP8.5 to reflect their impact on the net energy flows into the climate system. So RCP2.6 (4.5) would give rise to a net energy inflow to the climate system of 2.6 (4.5) Watts per square metre (Wm^2) by 2100 in the Integrated Assessment Model (IAM) used to derive them. These RCPs have been used as input to models that produce detailed simulations of the climate system.
7. In their Fifth Assessment Report, the IPCC analysed over 1 000 published emissions scenarios from integrated assessment models (IPCC, 2014a). Based on a subset of these selected for their detailed information on emissions and consistency with both historical emissions and assumptions about a feasible maximum level of negative emissions, the UK Meteorological Office Hadley Centre (MOHC) identified 39 scenarios that had a greater than 66% probability of not leading to warming above 2°C. These are shown in Figure 2.4 alongside scenarios that lead to median end of century warming of 1.75-2.0°C.
8. Estimates of the equilibrium climate sensitivity, which determines the long-run climate response to GHGs, range between 1.5°C and 4.5°C for a doubling of atmospheric CO_2 concentrations.
9. The net effect of negative emissions technologies on atmospheric concentrations is reduced by the response of the ocean and land stores of CO_2 to a reduction in atmospheric CO_2 concentration. See Mackey et al. (2013).
10. The climate effects of different GHGs relative to CO_2 are typically evaluated using the 100 year global warming potential (GWP_{100}), which also has been adopted in GHG trading schemes. However, this metric is not related to temperature outcomes, nor does it clearly highlight the need to limit cumulative CO_2 emissions (Smith et al., 2012). Indeed, there is no single metric that can equate the full climate effects of different GHGs as the appropriate metric will depend on the policy outcome sought (Shine, 2009).
11. To gain the same climatic benefit as a one-off reduction in the level of CO_2 emissions, the rate of methane emissions would need to be reduced on a permanent basis. Much of the difficulty in reducing CH_4 emissions lies in the agricultural sector and, in particular, with growing livestock numbers (Ripple et al., 2014).
12. About 70% of global N_2O emissions are due to agriculture (World Bank, 2009).
13. From the SSP Public Database Version 1.1. – see https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about
14. The climate policy assumptions for SSP2 – the SSP scenario that most closely resembles historic economic and demographic trends - include some delay in establishing global action with regions transitioning to global co-operation between 2020 and 2040, making emissions in the SSP2 baseline scenario broadly consistent with the NDCs (O'Neill et al., 2015; Riahi et al., 2017).
15. The industrial process emissions are estimated from the overall carbon budget (90 $GtCO_2$ over 2015-2100) with a starting point of 2 $GtCO_2$/yr and falling to around 1 $GtCO_2$/yr by 2050, as described on p.48 of IEA (2017).
16. Modelling approaches to land-use are highly varied – see Alexander et al. (2017).
17. In Brazil, concerted public action has led to reduced deforestation over the past few years.

18. The income groups are the standard World Bank groups, notably High-Income (HIC), Upper Middle-Income (UMIC) and Lower Middle-Income (LMIC) countries. There are no low-income countries (LIC) in the G20.
19. By including LULUCF emissions in the total, emissions increase (decrease) if land-use is a net source (sink).
20. In Japan, Korea, Russia, Turkey and the United States.
21. Canada, India and Mexico.
22. Analysis of the IPCC AR5 integrated assessment scenarios, consistent with outcomes with a greater than 66% likelihood of keeping warming below 2°C, result in total GHGs emissions in 2050 between 41%- to 72% lower than in 2010 (IPCC, 2014a), which in average annual terms requires emissions reductions between of 1.3%- to 3.1% per year. If world GDP is assumed to grow at around 3% per year, this would require the sum of the total annual reductions in the emissions intensity of GDP of some 4.3% to 6.1%.
23. The IEA's average figure for the G20 is based on more disaggregated modelling, not shown in the figure.
24. For example the use of advanced technology in some countries while other countries with a similar level of energy intensity might have developed in such a way because of constraints on energy availability.
25. Using more of the indicators discussed in this chapter would provide an alternative grouping based on cluster analysis. However there would be only minor differences, in part reflecting the importance of AFOLU emissions. To match the economic analysis in Chapter 4, which does not consider AFOLU sectors, we present the results based on this more limited number of characteristics.
26. See the Executive Summary of the 2015 DDPP report at http://deepdecarbonization.org/wp-content/uploads/2015/12/DDPP_EXESUM-1.pdf .
27. The G20 countries where no results are available are: Argentine, Russia, Saudi Arabia and Turkey.
28. See for e.g. Anandarajah and Gambhir (2014), Capros et al. (2014), Gambhir et al (2013), Pye et al. (2017), and Winkler and Marquand (2009).
29. Due to their high wealth and low protection level, three American cities (Miami, New York City and New Orleans) concentrated 31% of the losses in 2005 across the 136 cities studied. Adding Guangzhou, the four top cities accounted for 43% of global losses in that same year (Hallegatte et al., 2013).
30. A number of G20 countries have invested significantly in providing access to relevant data sources, through initiatives such as the UK's Climate Impact Programme and the climate section of the United States' US Data.Gov website. The private sector is increasingly engaged in this area, through the provision of consultancy services and provision of expertise by insurance companies.
31. Interactions between mitigation and adaptation will be explored in the 2018 IPCC special report on the impacts of global warming of 1.5°C degrees (IPCC, 2016).
32. The need for international environmental agreements to be "self-enforcing" in the face of limited sanctions had the dismaying implication that participation would be inefficiently low from a global perspective precisely when such co-operation would be of greatest environmental benefit (Barrett, 1994). Concerns about "carbon leakage" by through the off-shoring of emissions-intensive industry are a further constraint on stringent mitigation action, though at current levels of carbon prices there is little evidence that carbon leakage is a major problem, except perhaps in a few fossil-intensive industries. See for example, Branger, Quirion and Chevallier (2013) and Martin et al. (2014).
33. Leading to important debates about the right discount rate to use to estimate the social cost of carbon, see Pindyck (2013) for a discussion of this and related issues.
34. See Crampton et al., 2017.
35. NDCs representing 190 parties had been submitted as of 17 January 2017.
36. Of course, whether the NDCs are consistent with a goal of well below 2°C also depends on what happens to emissions beyond the 2025-30 period for which the NDCs are applicable. A comparison of countries' pledges with emission scenarios available in the IPCC AR5 database shows that more than three quarters of the scenarios that follow a similar emission profile to that consistent with existing NDCs to 2030 give median warming values of more than 2°C in 2100 (i.e. 50% chance of warming less than 2°C), with the vast majority giving a level of median warming between 2° and 3°C.

37. Aldy and Pizer (2016) use four integrated assessment models to assess and compare the NDCs. They estimate that countries' marginal abatement costs vary by two orders of magnitude. Marginal costs rise almost proportionally with income, while total mitigation costs also reflect carbon intensity and trade in fossil fuels. See also Bataille et al. (2016) and Rogelj et al. (2016a).
38. CO_2, CH_4, N_2O, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride.
39. See Arent and Tol (2014).
40. Concerns about "top-down" approaches crystallised at the Copenhagen UNFCCC Conference of the Parties (COP15) in 2009. Outcomes at COP16 in Cancún built on the Copenhagen Accord both in terms of a new transparency regime and a formalisation of some international pledges (e.g. on climate finance). More than 90 countries, including all major emitters, put forward pledges that took a variety of forms, mostly covering the period to 2020.
41. Ostrom (1990) highlighted the significant empirical evidence of the potential for self-organising institutions successfully to manage natural resources where there is sufficient trust and reciprocity between those involved. The likelihood of co-operation was also found to increase with factors such as: (i) reliable information about short- and long-term costs and benefits; (ii) a recognition of the importance of the resource to their own achievements and a long-term view; (iii) communication between those involved; (iv) informal monitoring and sanctioning is both feasible and considered appropriate; and (v) the existence of social capital and leadership.
42. The main milestones are the Facilitative Dialogue in 2018 and the Global Stocktakes, which will take place every five years from 2023 assess collective progress towards long term goals, including mitigation and adaptation efforts and means of implementation, and will inform Parties' future actions.
43. Countries agreed in Marrakesh at the 22nd Conference of the Parties (COP22) that this "Paris rulebook" will be finalised by the end of 2018 (COP24).

References

Aldy, J. and W. Pizer (2016), "Alternative metrics for comparing domestic climate change mitigation efforts and the emerging international climate policy architecture", *Review of International Economics and Policy, Vol. 10/1, Wiley, Hoboken, pp. 3-24,* http://dx.doi.org/10.1093/reep/rev013.

Alexander, P., et al. (2017), "Assessing uncertainties in land cover projections", *Global Change Biology, Vol. 23/2, Wiley, Hoboken, pp. 767-781,* http://dx.doi.org/10.1111/gcb.13447.

Allen, M.R., et al. (2016), "New use of global warming potentials to compare cumulative and short-lived climate pollutants", *Nature Climate Change, Vol. 6, Springer Nature, London, pp. 773-776,* http://dx.doi.org/10.1038/nclimate2998.

Allen, M.R., et al. (2009), "Warming caused by cumulative carbon emissions towards the trillionth tonne", *Nature*, Vol. 458, Springer Nature, London, pp.1163-1166, http://dx.doi.org/10.1038/nature08019.

Anandarajah, G. and A. Gambhir (2014), "India's CO_2 emission pathways to 2050: What role can renewables play?", *Applied Energy, Vol. 131, Elsevier, Amsterdam, pp.*79-86, http://doi.org/10.1016/j.apenergy.2014.06.026.

Arent, D.J. and R.S.J. Tol (2014), "Chapter 10: Key economic sectors and services", In: *Climate Change 2014: Mitigation of Climate Change*, IPCC Working Group III Contribution to AR5, Cambridge University Press, Cambridge, www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter5.pdf.

AVOID2 (2015), "AVOID2 climate change research programme", http://www.avoid.uk.net/indcs/ (accessed 12 December 2016).

Barrett, S. (1994), "Self-enforcing international environmental agreements", *Oxford Economic Papers*, Vol. 43, Oxford University Press, Oxford, pp. 878-894, www.jstor.org/stable/2663505.

Bataille, C., et al. (2016), "The need for national deep decarbonisation pathways for effective climate policy", *Climate Policy, Vol. 16, Supplement 1, Taylor & Francis, London, pp. S7-S26,* http://dx.doi.org/10.1080/14693062.2016.1173005.

Béguin, A., et al. (2011), "The Opposing Effects of Climate Change and Socio-Economic Development on the Global Distribution of Malaria", *Global Environmental Change*, Vol. 21/4, Elsevier, Amsterdam, pp. 1209-1214, http://doi.org/10.1016/j.gloenvcha.2011.06.001.

Blanco, G., et al. (2014), "Drivers, trends and mitigation", *Climate Change 2014: Mitigation of Climate Change, IPCC Working Group III Contribution to AR5. Cambridge University Press, Cambridge and New York,* www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter5.pdf.

Branger, F., P. Quirion and J. Chevallier (2013), "Carbon leakage and competitiveness of cement and steel industries under the EU ETS: much ado about nothing", *CIRED Working Paper Series,* www2.centre-cired.fr/IMG/pdf/CIREDWP-201353.pdf.

Capros, P., et al. (2014), "European decarbonisation pathways under alternative technological and policy choices: A multi-model analysis", *Energy Strategy Reviews, Vol. 2, Elsevier, Amsterdam, pp. 231-245,* http://dx.doi.org/10.1016/j.esr.2013.12.007.

Challinor, A.J., et al, (2014), "A meta-analysis of crop yield under climate change and adaptation", *Nature Climate Change, Vol. 4/4, Springer Nature, London, pp.287-291,* http://dx.doi.org/10.1038/nclimate2153.

Ciais, P., et al. (2013), "Carbon and other biogeochemical cycles", in Stocker et al. (eds.), *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York* www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter06_FINAL.pdf.

Crampton, P., et al. (eds.) (2017), *Global Carbon Pricing: The Path to Climate Cooperation, MIT Press, Cambridge, Massachusetts,* https://mitpress.mit.edu/books/global-carbon-pricing.

Creutzig, F., et al. (2015), "Bioenergy and climate change mitigation: an assessment", *Global Change Biology Bioenergy, Vol. 7/5, Wiley, Hoboken, pp.916-944,* http://dx.doi.org/10.1111/gcbb.12205.

DeAngelis, A., et al. (2010), "Observational evidence of enhanced precipitation due to irrigation over the Great Plains of the United States", *Journal of Geophysical Research*, Vol. 115, Issue D15, Wiley, Hoboken, http://dx.doi.org/10.1029/2010JD013892.

DDPP (Deep Decarbonization Pathways Project) (2015), *Pathways to Deep Decarbonization,* 2015 report – executive summary, Sustainable Development Solutions Network and Institute for Sustainable Development and International Relations, Paris, http://deepdecarbonization.org/wp-content/uploads/2015/06/DDPP_EXESUM.pdf.

Dunne, J.P., et al. (2013) "Reductions in labour capacity from heat stress under climate warming", *Nature Climate Change, Vol. 3, Springer Nature, London, pp. 563-566,* http://dx.doi.org/10.1038/nclimate1827.

EM-DAT (n.d.), *EM-DAT: The International Disaster Database,* www.emdat.be/ (accessed 9 February 2017).

FAO (2016), *FAOSTAT, Statistics Division, Food and Agriculture Organization of the United Nations, Rome Italy (accessed December 2016),* www.fao.org/faostat/en/.

FAO (2013), "Feeding the world", in FAO (2013), FAO Statistical Yearbook 2013, Part 3, FAO, Rome, www.fao.org/docrep/018/i3107e/i3107e00.htm

Friedlingstein, P., et al. (2014), "Persistent growth of CO_2 emissions and implications for reaching climate targets", *Nature Geoscience, Vol. 7, Springer Nature, London, pp.709-715,* http://dx.doi.org/10.1038/ngeo2248.

Fuss, S., et al. (2014), "Betting on negative emissions", *Nature Climate Change, Vol. 4, Springer Nature, London, pp. 850-853,* http://dx.doi.org/10.1038/nclimate2392.

Gambhir, A., et al. (2013), "A hybrid modelling approach to develop scenarios for China's carbon dioxide emissions to 2050", *Energy Policy, Vol. 59, Elsevier, Amsterdam, pp.614-632,* http://doi.org/10.1016/j.enpol.2013.04.022.

Hallegatte, S., et al. (2017), "Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters", *Climate Change and Development Series, World Bank, Washington DC,* http://dx.doi.org/10.1596/978-1-4648-1003-9.

Hallegatte, S., et al. (2016), "Shock Waves: Managing the Impacts of Climate Change on Poverty", *Climate Change and Development Series, World Bank Group, Washington, DC,* http://hdl.handle.net/10986/22787.

Hallegatte, S., et al. (2013), "Future flood losses in major coastal cities", *Nature Climate Change*, Vol. 3, Springer Nature, London, pp. 802-806, http://dx.doi.org/10.1038/nclimate1979.

Haasnoot, M., et al. (2013), "Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world", *Global Environmental Change, Vol. 23, pp.* 485-498, http://doi.org/10.1016/j.gloenvcha.2012.12.006.

Hosonuma, N., et al. (2012), "An assessment of deforestation and forest degradation in developing countries", *Environmental Research Letters, Vol. 7/4, IOP Publishing, Bristol,* http://dx.doi.org/10.1088/1748-9326/7/4/044009.

Huitema, D., et al. (2016), "The governance of adaptation: choices, reasons, and effects: Introduction to the Special Feature", *Ecology and Society, Vol. 21/3, Resilience Alliance, Wolfville, Nova Scotia,* http://dx.doi.org/10.5751/ES-08797-210337.

IEA (2017), "IEA finds CO_2 emissions flat for third straight year even as global economy grew in 2016", Press release, 17 March 2017, https://www.iea.org/newsroom/news/2017/march/iea-finds-co2-emissions-flat-for-third-straight-year-even-as-global-economy-grew.html.

IEA (2017), Chapters 1 and 2 in *Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System, International Energy Agency*, OECD Publishing, Paris, www.energiewende2017.com/wp-content/uploads/2017/03/Perspectives-for-the-Energy-Transition_WEB.pdf.

IIASA (n.d.), *SSP Database*, International Institute for Applied Systems Analysis, Laxenburg, Austria, https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about./.

Ignaciuk, A. and D. Mason-D'Croz (2014), "Modelling adaptation to climate change in agriculture", *OECD Food, Agriculture and Fisheries Papers*, No. 70, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jxrclljnbxq-en.

IPCC (2016), *Decision IPCC/XLIV-4, Sixth Assessment Report (AR6) Products, Outline of the Special Report on 1.5°C*, 44th session of the IPCC Panel, Bangkok (Thailand), 17-20 October 2016, Intergovernmental Panel on Climate Change, Geneva, www.ipcc.ch/meetings/session44/l2_adopted_outline_sr15.pdf.

IPCC (2014a), *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Cambridge University Press, Cambridge, and New York,* http://www.ipcc.ch/report/ar5/wg3/.

IPCC (2014b), "Summary for policymakers", in Field et al. (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York, pp. 1-32.*

IPCC (2014c), *Climate Change 2014: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, Geneva, www.ipcc.ch/report/ar5/syr/.

IPCC (2013), *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*", Cambridge University Press, Cambridge and New York, www.ipcc.ch/report/ar5/wg1/.

Lenton, T.M. et al. (2008), "Tipping elements in the Earth's climate system", *Proceedings of the National Academy of Sciences, Vol. 105/6, National Academy of Sciences of the United States of America, Washington DC, pp.1786-1793,* http://dx.doi.org/10.1073/pnas.0705414105.

Lowe, J.A., et al. (2009), "How difficult is it to recover from dangerous levels of global warming?", *Environmental Research Letters, Vol. 4/1, IOP Publishing, Bristol,* http://dx.doi.org/10.1088/1748-9326/4/1/014012.

Luo, T., et al. (2013), *Majority of China's proposed coal-fired power plants located in water-stressed regions, World Resources Institute, Washington,* www.wri.org/blog/2013/08/majority-china%E2%80%99s-proposed-coal-fired-power-plants-located-water-stressed-regions.

Mackey, B., et al. (2013), "Untangling the confusion around land carbon science and climate change mitigation policy", *Nature Climate Change, Vol. 3/6, Springer Nature, London, pp.*552-557, http://dx.doi.org/10.1038/nclimate1804.

Martin, R., et al. (2014), "On the empirical content of carbon leakage criteria in the EU Emissions Trading Scheme", *Ecological Economics, Vol. 105, Elsevier, Amsterdam, pp.78-88,* http://doi.org/10.1016/j.ecolecon.2014.05.010.

MCTI (2016), *Annual Estimates of GHG Emissions in Brazil*, Ministry of Science, Technology and Innovation, Brasilia, Brazil, http://seeg.eco.br/2014/12/06/seeg-2014-engl/.

Moss, R.H. et al. (2010), "The next generation of scenarios for climate change research and assessment", *Nature, Vol. 463, Springer Nature, London, pp. 747-756,* http://dx.doi.org/10.1038/nature08823.

Myhre, G. and D. Shindell (2013), "Anthropogenic and Natural Radiative Forcing – Supplementary Material", In Stocker et al. (eds.), *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York,* www.ipcc.ch/pdf/assessment-report/ar5/wg1/supplementary/WG1AR5_Ch08SM_FINAL.pdf.

Nemet et al. (2017), "Addressing policy credibility problems for low-carbon investment", *Global Environmental Change, Vol. 42, Elsevier, Amsterdam, pp.474-57,* http://doi.org/10.1016/j.gloenvcha.2016.12.004.

NOAA (2017), *Trends in atmospheric carbon dioxide*, U.S. National Oceanic and Atmospheric Administration, Silver Spring, Maryland, www.esrl.noaa.gov/gmd/ccgg/trends/.

OECD (forthcoming), *Biodiversity and Development: Mainstreaming and Managing for Results,* OECD Publishing, Paris.

OECD (2017), «Air and climate: Greenhouse gas emissions by source», *OECD Environment Statistics* (database).DOI: http://dx.doi.org/10.1787/data-00594-en (accessed 28 March 2017).

OECD (2016a), *Policy Guidance on Resource Efficiency,* OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264257344-en.

OECD (2016b), *Summary record of the 8th OECD Food Chain Analysis Network Meeting – 23-24 June 2016, OECD, Paris* www.oecd.org/site/agrfcn/meetings/FCAN%20June%202016%20Summary%20Report_for%20website.pdf.

OECD (2015a), *Climate Change Mitigation: Policies and Progress*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264238787-en.

OECD (2015b), *The Economic Consequences of Climate Change*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264235410-en.

OECD (2015c), *Climate Change Risks and Adaptation: Linking Policy and Economics*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264234611-en.

OECD (2015d), *National Climate Change Adaptation: Emerging Practices in Monitoring and Evaluation*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264229679-en.

OECD (2015e), "Key joint messages emerging from the OECD-France Conference on Agriculture and agricultural soils facing climate change and food security challenges: public policies and practices", 16 September 2015, OECD, Paris, www.ag4climate.org/keymessages/.

OECD (2014), *Green Growth Indicators for Agriculture: A Preliminary Assessment*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264223202-en.

OECD (2012), *OECD Environmental Outlook to 2050: The Consequences of Inaction*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264122246-en.

OECD (2010), *Paying for Biodiversity: Enhancing the Cost-Effectiveness of Payments for Ecosystem Services, OECD Publishing, Paris,* http://dx.doi.org/10.1787/9789264090279-en.

Olivier, J.G.J., et al. (2016), *Trends in global CO_2 emissions: 2016 Report, European Commission, Joint Research Centre (JRC), Directorate C – Energy, Transport and Climate; PBL Netherlands Environmental Assessment Agency, The Hague,* http://edgar.jrc.ec.europa.eu/news_docs/jrc-2016-trends-in-global-co2-emissions-2016-report-103425.pdf.

Olsson, L., et al. (2014), "Livelihoods and poverty", in *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge and New York, pp. 793-832, http://danida.vnu.edu.vn/cpis/files/IPCC/wg2/pdf/WGIIAR5-Chap13_FINAL.pdf.

O'Neill, B.C., et al. (2015), "The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century", *Global Environmental Change, Vol.*42, Elsevier, Amsterdam, pp. 169-180, http://dx.doi.org/10.1016/j.gloenvcha.2015.01.004.

Ostrom, E. (2009), "A General Framework for Analyzing Sustainability of Social-Ecological Systems", *Science, Vol. 325/5939, American Association for the Advancement of Science, New York, pp.* 419-422, http://dx.doi.org/10.1126/science.1172133.

Ostrom, E. (1990), *Governing the Commons: The Evolution of Institutions for Collective Action, Cambridge University Press, Cambridge and New York.*

Peters, G.P., et al. (2017), "Key indicators to track current progress and future ambition of the Paris Agreement", Nature Climate Change, Vol. 7/2, Springer Nature, pp.118-122, http://dx.doi.org/ 10.1038/nclimate3202.

Pindyck, R.S. (2013), "Climate change policy: What do the models tell us?", *Journal of Economic Literature, Vol. 51/3, American Economic Association, Pittsburgh, pp.*860-872, http://dx.doi.org/10.1257/jel.51.3.860.

Popp, A., et al. (2017), "Land-use futures in the shared socioeconomic pathways", *Global Environmental Change, Vol. 42,* Elsevier, Amsterdam, pp. 331-345, http://dx.doi.org/10.1016/j.gloenvcha.2016.10.002.

Prentice, I.C., Williams, S. and P. Friedlingstein (2015), "Biosphere feedbacks and climate change", *Grantham Institute Briefing Paper No.12, Imperial College London, London,* https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/Biosphere-feedbacks-and-climate-change-Briefing-Paper-No-12v2.pdf.

Pye, S., et al. (2017), "Achieving net-zero emissions through the reframing of UK national targets in the post-Paris Agreement era", *Nature Energy, Vol. 2, Springer Nature, London,* http://dx.doi.org/10.1038/nenergy.2017.24.

Revi, A., et al. (2014), "Urban Areas", in Field, C.B. et al. (eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability: Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge and New York, pp. 535-612, http://ar5-syr.ipcc.ch/ipcc/ipcc/resources/pdf/WGII/WGIIAR5-Chap8_FINAL.pdf.

Riahi, K., et al. (2017), "The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview", *Global Environmental Change, Vol. 42,* Elsevier, Amsterdam, pp.153-168, http://dx.doi.org/10.1016/j.gloenvcha.2016.05.009.

Ripple, W.J., et al. (2014), "Ruminants, climate change and climate policy", *Nature Climate Change, Vol. 4/1, Springer Nature, pp.2-5,* http://dx.doi.org/10.1038/nclimate2081.

Rittel, H.W. and M.M. Webber (1973) "Dilemmas in a general theory of planning", *Policy Sciences, Vol. 4/2, Springer Nature, London, pp.155-169,* http://dx.doi.org/10.1007/BF01405730.

Rogelj, J., et al. (2016a), "Paris Agreement climate proposals need a boost to keep warming below 2°C", *Nature, Vol. 534/7609, Springer Nature, London, pp. 631-639,* http://dx.doi.org/10.1038/nature18307.

Rogelj, J., et al. (2016b), "Differences between carbon budget estimates unravelled", *Nature Climate Change*, Vol. 6/3, Springer Nature, London, pp. 245-252, http://dx.doi.org/10.1038/nclimate2868.

Rose, S. K., et al. (2014), "Bioenergy in energy transformation and climate management", *Climatic Change, Vol. 123/3, Springer Nature, pp. 477-493,* http://dx.doi.org/10.1007/s10584-013-0965-3.

Sadoff, C.W., et al. (2015) *Securing Water, Sustaining Growth: Report of the GWP/OECD Task Force on Water Security and Sustainable Growth*, University of Oxford, Oxford, www.water.ox.ac.uk/wp-content/uploads/2015/04/SCHOOL-OF-GEOGRAPHY-SECURING-WATER-SUSTAINING-GROWTH-DOWNLOADABLE.pdf.

Schiermeier, Q. (2007), "The new face of the article", *Nature, Vol. 446/7132, Springer Nature, London, pp. 133-135,* http://dx.doi.org/10.1038/446133a.

Settele, J., et al. (2014), "Terrestrial and inland water systems", in Field, C.B. et al. (eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York, pp. 271-359,* www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap4_FINAL.pdf.

Shepherd, T.G. (2014), "Atmospheric circulation as a source of uncertainty in climate change projections", *Nature Geoscience, Vol. 7/10, Springer Nature, pp.703-708,* http://dx.doi.org/10.1038/ngeo2253.

Shindell, D., et al. (2012), "Simultaneously mitigating near-term climate change and improving human health and food security", *Science, Vol. 335/6065, American Association for the Advancement of Science, New York, pp. 183-189,* http://dx.doi.org/10.1126/science.1210026.

Shine, K.P. (2009), "The global warming potential—The need for an interdisciplinary retrial", *Climatic Change, Vol. 96/4, Springer Nature, pp.467-472,* http://dx.doi.org/10.1007/s10584-009-9647-6.

Smith, P. (2016), "Soil carbon sequestration and biochar as negative emission technologies", *Global Change Biology, Vol. 22/3, Wiley, Hoboken, pp.1315-1324,* http://dx.doi.org/10.1111/gcb.13178.

Smith, P., et al. (2015), "Biophysical and economic limits to negative CO_2 emissions", *Nature Climate Change, Vol. 6, Springer Nature, London, pp.42-50,* http://dx.doi.org/ 10.1038/nclimate2870.

Smith, P., et al. (2014), "Agriculture, Forestry and Other Land Use (AFOLU)", in Edenhofer et al. (eds.), *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York,* www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter11.pdf.

Smith, P., et al. (2013), "How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals?", *Global Change Biology, Vol. 19/8, Wiley, Hoboken, pp.2285-2302,* http://dx.doi.org/10.1111/gcb.12160.

Smith, K.R., et al. (2014), "Human health: impacts, adaptation, and co-benefits", in Field et al. (eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York,* www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap11_FINAL.pdf.

Smith, S.M., et al. (2012), "Equivalence of greenhouse-gas emissions for peak temperature limits", *Nature Climate Change, Vol. 2/7, Springer Nature, London, pp.535-538,* http://dx.doi.org/ 10.1038/nclimate1496.

Solomon, S., et al. (2009), "Irreversible climate change due to carbon dioxide emissions", *Proceedings of the National Academy of Sciences, Vol. 106, National Academy of Sciences of the United States of America, pp. 1704-1709,* http://dx.doi.org/10.1073/pnas.0812721106.

Steffen, W., et al. (2004), *Global Change and the Earth System: A Planet Under Pressure, Springer-Verlag, Berlin and Heidelberg.*

Stern, N.H. (2007), The economics of climate change: the Stern review, Cambridge University Press, Cambridge.

Taylor, K., R. Stouffer and G. Meehl (2012), *An Overview of CMIP5 and the Experiment Design*, AMS, http://dx.doi.org/10.1175/BAMS-D-11-00094.1.

UNEP (2015), *The Emissions Gap Report 2015: A UNEP Synthesis Report, United Nations Environment Programme,* http://web.unep.org/emissionsgapreport2015.

UNFCCC (n.d.), *NDC Registry (interim) (accessed 9 February 2017),* www4.unfccc.int/ndcregistry/Pages/All.aspx.

UNFCCC (2016), *National Inventory Submissions 2016: CRF tables.* http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/9492.php.

UNFCCC (2015a), *Paris Agreement,* http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf.

UNFCCC (2015b), *Synthesis report on the aggregate effect of the intended nationally determined contributions, FCCC/CP/2015/7,* http://unfccc.int/focus/indc_portal/items/9240.php.

UNFCCC (2014), *GHG emission profiles for non-Annex I Parties* (accessed 29 March 2017). http://unfccc.int/ghg_data/ghg_data_unfccc/ghg_profiles/items/4626.php.

Vallejo, L. and M. Mullan (2017), "Climate-resilient infrastructure: Getting the policies right", *OECD Environment Working Papers*, No. 121, OECD Publishing, Paris, http://dx.doi.org/10.1787/02f74d61-en.

Wigley, T.M., R. Richels and J.A. Edmonds (1996), "Economic and environmental choices in the stabilization of atmospheric CO_2 concentrations", *Nature, Vol. 379/6562, Springer Nature, London, pp.240,* http://dx.doi.org/10.1038/379240a0.

Wilbanks, T. (2005), "Issues in developing a capacity for integrated analysis of mitigation and adaptation", *Environmental Science and Policy, Vol. 8/6, pp.* 541-547, http://dx.doi.org/10.1016/j.envsci.2005.06.014.

Winkler, H. and A. Marquand (2009), "Changing development paths: From an energy-intensive to low-carbon economy in South Africa", *Climate and Development, Vol. 1/1, Taylor & Francis, London, pp.47-65,* http://hdl.handle.net/11427/16928.

Wise, R.M., et al. (2014), "Reconceptualising adaptation to climate change as part of pathways of change and response", *Global Environmental Change*, Elsevier, Amsterdam, Vol. 28, pp. 325-336, http://doi.org/10.1016/j.gloenvcha.2013.12.002.

World Bank (n.d.a), *World Development Indicators Database,* (accessed February 2017), World Bank, Washington DC, http://data.worldbank.org/data-catalog/world-development-indicators.

World Bank (n.d.b.), *World Governance Indicators Database,* (accessed February 2017), World Bank, Washington DC, http://info.worldbank.org/governance/wgi/#home.

World Bank (2016), "Highlights: Featuring the Sustainable Development Goals", in *2016 World Development Indicators*, World Bank, Washington DC, http://databank.worldbank.org/data/download/site-content/wdi-2016-highlights-featuring-sdgs-booklet.pdf.

World Bank (2009), *World Development Indicators 2008,* World Bank, Washington DC, http://documents.worldbank.org/curated/en/587251468176971009/World-development-indicators-2008.

WHO (World Health Organisation) (2014), "Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s", WHO, Geneva, www.who.int/globalchange/publications/quantitative-risk-assessment/en/.

WMO (World Meteorological Organization) (2017), *Statement on the State of the Global Climate in 2016, WMO-No. 1189, WMO, Geneva,* http://library.wmo.int/opac/doc_num.php?explnum_id=3414.

Zhang, X., et al. (2015), "Managing nitrogen for sustainable development", *Nature*, Vol. 528/7580, Springer Nature, London, pp.51-59, http://dx.doi.org/10.1038/nature15743

Annex 2.A1. Summary of G20 countries' (I)NDCs

Summary of G20 countries' (I)NDCs

G20 ECONOMY	TYPE	BASE YEAR	TARGET DATE	CONDITIONALITY	GHG EMISSIONS MITIGATION TARGET	SECTORS COVERED	GASES COVERED	MITIGATION MEASURES	ADAPTATION MEASURES
ARGENTINA	Emission ceiling	n/a	By 2030	Unconditional	To not exceed 483 $MtCO_2eq$	Economy-wide, including energy, industrial processes, agriculture (including cattle rearing), LULUCF, waste	CO_2, CH_4, N_2O, HFC, PFC, SF6	Action on sustainable forestry, energy efficiency, biofuels, nuclear power, renewable energy and transport modal shift	1. Early warning mechanisms and systems for response and recovery from climate disasters 2. Sustainable management of native forests 3. Water resource management 4. Crop management 5. Management of the health impacts of climate change 6. Implementation of measures to face extreme events 7. Ecosystem-based biodiversity conservation and adaptation
	Emission ceiling			Conditional on financial, technical and capacity-building support from abroad	To not exceed 369 $MtCO_2eq$				
AUSTRALIA	Absolute reduction from base year emissions	2005	By 2030	Unconditional	Reduction of 26-28%	Economy-wide, including energy, industrial processes and product use, agriculture, LULUCF, waste	CO_2, CH_4, N_2O, HFC, PFC, SF6, NF_3	1. Emissions Reduction Fund – provides incentives for emissions reduction activities across the economy. 2. Safeguard Mechanism – sets emissions limits for facilities emitting >100 000 tonnes per year. 3. Renewable Energy Target of 23% of electricity supply to come from renewable sources by 2020. 4. National Energy Productivity Plan to achieve a 40% improvement in energy productivity by 2030. 5. Grants for research, development, demonstration and deployment of clean energy technologies.	1. Work to build climate resilience and support adaptation to climate change. 2. Develop a National Climate Resilience and Adaptation Strategy.
BRAZIL	Absolute reduction from base year emissions	2005	By 2025	Unconditional	Reduction of 37%	Economy-wide, including emissions from forest managed areas (conservation units and indigenous lands)	Not specified	Not specified	Outlined in the National Adaptation Plan, which focuses on risk areas, housing, basic infrastructure (especially in the areas of health, sanitation and transportation).
	Absolute reduction from base year emissions	2005	By 2030	n/a	Reduction of 43% (indicative value, for reference only)				
CANADA	Absolute reduction from base year emissions	2005	By 2030	Unconditional	Reduction of 30%	Economy-wide (although excludes emissions from natural disturbances)	CO_2, CH_4, N_2O, HFC, PFC, SF6, NF_3	Regulation measures in the transport and energy sectors and with regards to renewable fuels	Not specified
CHINA	Peaking of emissions	n/a	By 2030	Not specified	n/a	Economy-wide	Not specified	ii) Increase the share of non-fossil fuels in primary energy consumption to approx. 20%. iii) Increase forest stock volume by 4.5 cubic meters compared with 2005 levels.	i) Enhance mechanisms and capacities for climate vulnerable sectors. ii) Strengthen early warning and emergency response systems.
	Emission intensity of GDP	2005	By 2030	Not specified	Reduction of 60-65%				

Summary of G20 countries' (I)NDCs *(cont.)*

G20 ECONOMY	TYPE	BASE YEAR	TARGET DATE	CONDITIONALITY	GHG EMISSIONS MITIGATION TARGET	SECTORS COVERED	GASES COVERED	MITIGATION MEASURES	ADAPTATION MEASURES
EUROPEAN UNION	Absolute reduction from base year emissions	1990	By 2030	Not specified	Reduction of 40%	Economy-wide, including energy, industrial processes and product use, agriculture, waste, LULUCF	CO_2, CH_4, N_2O, HFC, PFC, SF6, NF_3	Not specified	Not specified
INDIA	Emission intensity of GDP	2005	By 2030	Dependent on financial, technical and capacity-building support from developed countries	Reduction of 33-35%	Economy-wide	Not specified	*i)* Achieve 40% cumulative electric power installed capacity from non-fossil fuel based energy sources by 2030. *ii)* Create an additional carbon sink of 2.53 billion tCO_2eq through afforestation by 2030. *iii)* Introduce cleaner, more efficient technologies in thermal power generation. *iv)* Promotion renewables and increase the share of alternative fuels in the country's fuel mix. *v)* Reduce emissions from the transport and waste sectors. *vi)* Promote energy efficiency. *vii)* Fully implement India's afforestation programmes.	*i)* Enhance investment in development programs in vulnerable sectors. *ii)* Develop climate-resilient infrastructure. *iii)* Enhance climate-resilience more generally.
INDONESIA	Emission reduction relative to BAU baseline	BAU scenario of 2.869 $GtCO_2$-eq in 2030	By 2030	Unconditional	Reduction of 29%	Energy (including transport), industrial processes and product use, agriculture, LULUCF, waste	CO_2, CH_4, N_2O	LULUCF: Reducing deforestation and forest degradation, restoring ecosystem functions, sustainable forest management. Energy: 23% of energy coming from new and renewable energy by 2025 Waste: Enhance management capacity of urban wastewater, reduce landfill waste, using waste for energy production	Outlined in the National Action Plan on Climate Change Adaptation. Includes local capacity strengthening, improved knowledge management, identifying synergies between the adaptation and disaster risk reduction agendas, application of adaptive technologies.
	Emission reduction relative to BAU baseline			Dependent on financial, technical and capacity-building support from developed countries	Reduction of 41%				
JAPAN	Absolute reduction from base year emissions	FY 2013	By FY 2030	Not specified	Reduction of 26%	Economy-wide: Energy (incl. CO_2 from transport), industrial processes and product use, agriculture, LULUCF, waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6 and NF_3	INDC includes a 2030 target for *i)* final energy consumption: 326 M kl, *ii)* Japan's energy mix: 22-24% renewable energy (dominated by solar and hydropower), 2220% nuclear, 26% coal, 27% LNG, 3% oil. A detailed list of the policy measures considered for each sector is included as an annex to the NDC.	Not specified

Summary of G20 countries' (I)NDCs *(cont.)*

G20 ECONOMY	TYPE	BASE YEAR	TARGET DATE	CONDITIONALITY	GHG EMISSIONS MITIGATION TARGET	SECTORS COVERED	GASES COVERED	MITIGATION MEASURES	ADAPTATION MEASURES
KOREA	Emission reduction relative to BAU baseline	BAU of 850.6 $MtCO_2$-eq in 2030	By 2030	Not specified	Reduction of 37%	Economy-wide, excluding LULUCF (energy, industrial processes and product use, agriculture and waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6	Use of carbon credits to achieve 2030 mitigation target. Other mitigation measures used include i) an emissions trading scheme for the industrial sector (launched in 2015), ii) renewable energy regulations for the power sector, iii) a Green Building Standards Code and a system for the Performance Evaluation of Eco-friendly Homes for the buildings sector, iv) low-carbon standards for fuel efficiency and tax incentives to purchase electric vehicles in the transport sector.	Outlined in the National Climate Change Adaptation Plan (2010). *i)* strengthening infrastructure for climate change monitoring, forecasting and analysis; *ii)* developing a management system for disaster prevention and stable water supply; *iii)* developing a climate-resilient ecosystem; *iv)* making a systemic transition to a climate-resilient social and economic structure; and *v)* enhancing the system for the management of negative impacts of climate change on health.
MEXICO	Emission reduction relative to BAU baseline	BAU scenario projecting economic growth in the absence of climate policies	By 2030	Unconditional	Reduction of 25%	Nation-wide (Energy, Industrial processes and product use, agriculture, waste, LULUCF)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6, Black carbon	Mexico's mitigation commitment includes an unconditional reduction of GHG emissions of 22% by 2030. The target increases to 25% when Black Carbon is included.	*i)* Strengthen the adaptive capacity of at least 50% the most vulnerable municipalities. *ii)* Establish early warning systems and risk management at every level of government. *iii)* Reach a rate of 0% deforestation by the year 2030.
	Emission reduction relative to BAU baseline		By 2030	Conditional on financial, technical and capacity-building support from abroad, and international agreement on carbon price, carbon border adjustments.	Reduction of 40%				
RUSSIAN FEDERATION	Absolute reduction from base year emissions	1990	By 2030	Conditional on the maximum absorbing capacity of forests	Reduction of 25-30%	Economy-wide (Energy, industrial processes and product use, agriculture, LULUCF, waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6 and NF_3	Not specified	Not specified
SAUDI ARABIA	Emission reduction relative to BAU baseline	BAU scenario projecting economic growth in the absence of climate policies	By 2030	Conditional on the provision of technical assistance and capacity-building	Avoid 130 $MtCO_2eq$	Not specified	Not specified	*i)* Improve energy efficiency via the expansion of the Saudi Energy Efficiency Program, which currently only focuses on industry, buildings and transport sectors. *ii)* Develop renewable energy and natural gas exploitation to diversify the energy mix. *iii)* Develop CCUS via plans to construct a CCU plant able to capture 1 500 tCO_2 per day. *iv)* Recover methane and minimise flaring.	Focus on: *i)* water and wastewater management, *ii)* urban planning, *ii)* marine protection, *iv)* reducing desertification, *v)* developing integrated coastal zone management planning, *vi)* further developing early warning systems, and *vii)* develop integrated water management planning.

Summary of G20 countries' (I)NDCs *(cont.)*

G20 ECONOMY	TYPE	BASE YEAR	TARGET DATE	CONDITIONALITY	GHG EMISSIONS MITIGATION TARGET	SECTORS COVERED	GASES COVERED	MITIGATION MEASURES	ADAPTATION MEASURES
SOUTH AFRICA	Emissions peak, plateau and decline (starting 2020 year-end)	Peak, plateau, decline	Peak: 2020-2025, Plateau 2025-2035, Decline as of 2035	Conditional on the degree of implementation of the Convention by developed countries	Peak: 398-614 $MtCO_2$-eq	Economy-wide (Energy, industrial processes and product use, agriculture, LULUCF, waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6 (with a particular focus on CO_2, CH_4, N_2O)	Carbon tax, desired emission reduction outcomes for sectors, company-level carbon budgets, regulatory standards and controls.	*i)* Develop a National Adaptation Plan *ii)* Take climate considerations into account in development policy frameworks. *iii)* Build institutional capacity for climate change response planning and implementation *iv)* Develop early warning systems for climate vulnerable sectors *v)* Develop vulnerability assessment and adaptation needs framework *vi)* Communicate on adaptation efforts
TURKEY	Emission reduction relative to BAU baseline	BAU scenario projecting economic growth in the absence of climate policies	By 2030	Not specified, although NDC mentions that the country will receive financial, technological, and capacity-building support from abroad.	Reduction of up to 21%	Economy-wide (Energy, industrial processes and product use, agriculture, LULUCF, waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6 and NF_3	Use of carbon credits from international market mechanisms. An exhaustive list of the measures planned by sector is listed in the INDC.	Not specified
UNITED STATES	Absolute reduction from base year emissions	2005	By 2025	Not specified	Reduction of 26-28%	Economy-wide (energy, industrial processes and product use, agriculture, LULUCF, waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6 and NF_3	Does not intend to use international market mechanisms to reach 2025 target. Regulatory measures mitigate emissions include: *i)* fuel economy standards for light-duty and heavy-duty vehicles; *ii)* energy conservation standards for building appliances/equipment as well as building codes for building envelopes; *iii)* regulation to cut emissions from existing power plants; *iv)* methane-specific standards for landfills and the oil and gas sector *v)* the Significant New Alternatives Policy program (targets HFCs).	Not specified

Source: UNFCCC, n.d.

Chapter 3

Infrastructure for climate and growth

Infrastructure investment is vital to underpin economic growth and development, but current levels of investment are inadequate. Meeting the Paris Agreement's mitigation and adaptation objectives will also require a radical shift in the world's infrastructure base. This chapter considers the current gap in infrastructure investment, the infrastructure and technology transformations needed to shift onto low-emission, climate-resilient pathways, and the incremental capital costs involved. It then looks at the energy sector as an indicative assessment of progress in aligning infrastructure investment plans for the transition, before exploring how governments might better align short-term investment strategies with long-term decarbonisation and resilience goals.

Choices made today about the types, features and location of infrastructure will heavily influence the extent of the impacts of climate change and the vulnerability or resilience of societies to it. Creating low-emission, climate-resilient pathways compatible with the Paris Agreement, as described in Chapter 2, requires a radical shift in our infrastructure bases, mainly for energy, mobility services and buildings. Sustainable infrastructure – infrastructure that is socially, economically and environmentally sound – is a key foundation for economic activity and for reaching the Sustainable Development Goals (SDGs). Since the financial crisis, however, infrastructure of all kinds has suffered from chronic underinvestment.

The first section of this chapter documents the current gap in infrastructure investment required to sustain growth and development. The inconsistencies between current investment trends and climate goals, and the infrastructure investment and technology transformations needed to shift G20 governments onto low-emission, climate-resilient pathways are then addressed. The chapter then focuses on the energy sector as an indicative assessment of progress in aligning infrastructure investment plans for the transition, highlighting the risks of locking in emissions and stranding assets that come with continued investment in fossil-fuel infrastructure. Finally, the chapter concludes with guidance to G20 countries on how they could better align short-term investment strategies with long-term, low-emission decarbonisation goals, and the need to enhance resilience to climate impacts.

Scaling up infrastructure investment to sustain growth and development

Infrastructure in sectors such as energy, transport, water and telecommunications is the backbone of our economies, essential for sustained, inclusive growth and for meeting the SDGs. But current levels of investment in infrastructure are generally too low to sustain growth, and often of insufficient quality. Ensuring affordable and reliable access to basic services remains a major challenge in lower and middle-income countries, while advanced economies are struggling with chronic underinvestment in their ageing infrastructure. Infrastructure investment in the G20 countries needs to be significantly scaled up to fill this gap.

Current levels of infrastructure investment are insufficient to sustain growth and development

Effective energy and transport infrastructure underpins almost all economic activity. Many studies have underscored the positive relationship between high-quality public infrastructure and economy-wide productivity in the long run (e.g. Berg et al., 2012; Ghazanchyan and Stotsky, 2013; Calderon and Serven, 2014). Infrastructure investment is also a way of stimulating demand in the short term: after the financial crisis, many G20 countries devoted a major share of their fiscal stimulus to infrastructure investment (see Chapter 4). On average, emerging and developing economies devoted 40% of their stimulus packages to infrastructure spending, while advanced economies devoted 21% (ILO and IILS, 2011).

Infrastructure investment can also have an impact on promoting inclusive development and fighting income inequality. Inclusive growth, human well-being and poverty reduction depend critically on the type, extent and quality of the infrastructure that supports key services: food, energy, water supply, safe and resilient cities, and sustainable industrialisation (Bhattacharya et al., 2016a). For example, SDG7 (*"Ensure access to affordable, reliable, sustainable and modern energy for all"*) requires considerable investment in energy infrastructure in urban and rural areas. Investments in sustainable infrastructure can boost growth and employment and contribute to *"promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" (SDG8)*. Transport infrastructure – such as roads, railways, ports and airports – connects home to work, and rural areas to domestic and regional markets, contributing to economic development and the goal of "*ending poverty in all its forms everywhere*" (SDG 1). Infrastructure choices also affect our natural environment and the sustainable use of natural assets such as air, water, terrestrial ecosystems and forests (SDGs 13, 14 and 15).

Despite the links between infrastructure investment and growth and development, underinvestment in infrastructure has been chronic over the past decades. The stock of public capital relative to GDP decreased by 15% globally in the past 30 years (Bhattacharya et al., 2016b; IMF, 2014). Over the past two decades, global infrastructure investment has averaged 3.5% of world GDP (Woetzel et al., 2016).

In advanced G20 economies, public investment fell from 5% of GDP in the late 1960s to 3% in the mid-2000s. Despite increased infrastructure investment following the recent financial crisis, spending remains at a historic low, resulting in an ageing and poorly maintained infrastructure stock in many G20 countries. In the United States, for instance, the National Association of Manufacturers rates transport-related land-based infrastructure as mediocre to poor, with US bridges on average 42 years old, and 1 in 9 structurally deficient. In addition, 65% of roads in 2013 were in "less than good condition", a significant factor in 30% of road fatalities (National Economic Council and the President's Council of Economic Advisers, 2014).

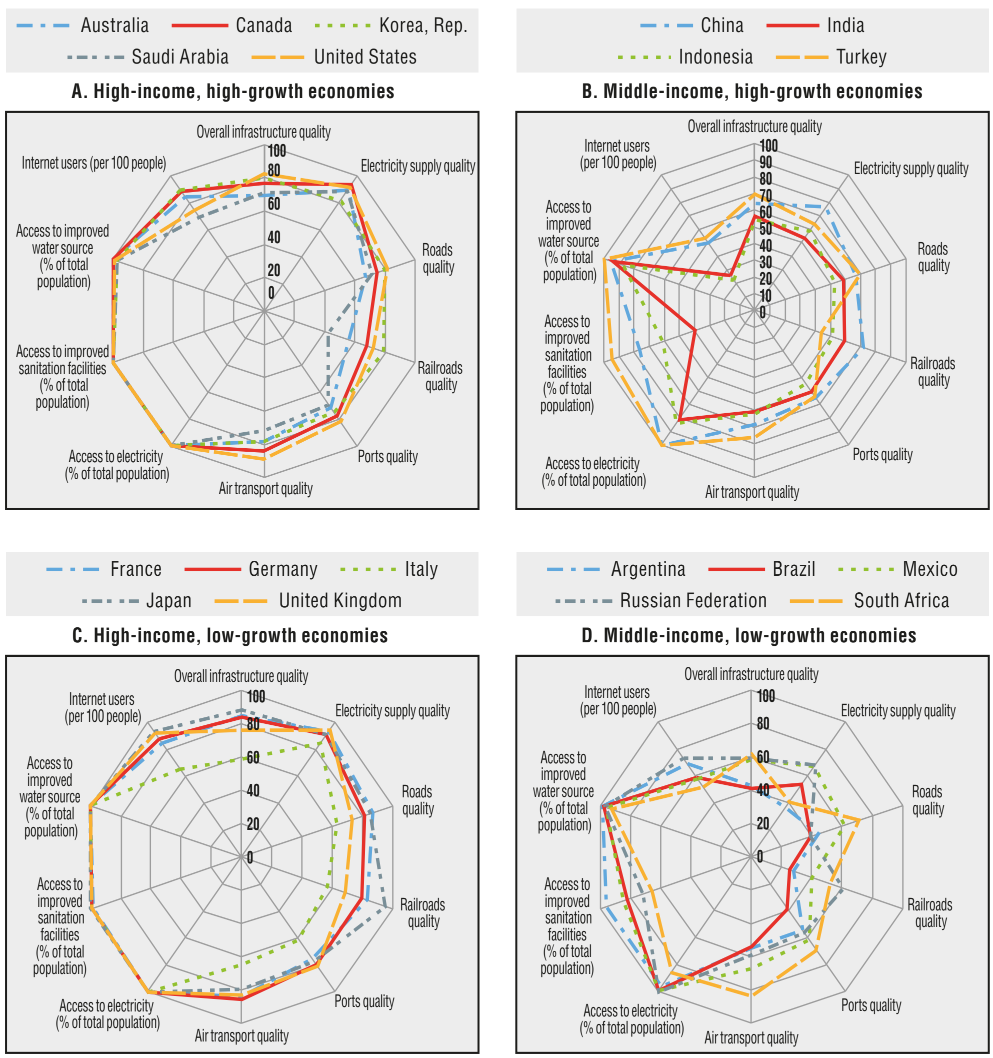
In emerging and low-income economies, public investment fell from 8% of GDP in the late 1970s to 4-5% in the mid-2000s, rising again to 6-7% in 2012. This increase has been led by China, which in 2014 accounted for USD 1.3 trillion of the USD 2.2 trillion invested in infrastructure in developing and emerging economies. This is not only more than all other developing countries, but also more than all developed countries combined (Bhattacharya et al., 2016b).

The quality of infrastructure is critical for development. Many middle-income economies – such as Brazil, India, Russia and South Africa – are left with infrastructure bases of low quality, which constrains medium- and near-term growth. In South Africa, for instance, only 46% of households had piped water of good quality in 2012 and only 71% of households had access to sewerage networks. One-fifth of South African firms identified unreliable electricity supply as a major constraint to doing business (Development Bank of Southern Africa, 2012). Even in China, despite sustained investment in the past decades, the quality of urban infrastructure is not always adapted to the challenges faced by rapidly growing cities (Pan, 2016). Some suggest that China has in fact overinvested in infrastructure and highlight a need to reallocate investments towards more productive infrastructure (Ansar et al., 2016).

Unprecedented levels of infrastructure investment are needed to *i)* maintain and upgrade ageing infrastructure in high-income countries; and *ii)* achieve universal access to basic services in middle-income economies. G20 countries face different priorities in improving infrastructure quality and access (Figure 3.1). Rapid rates of urbanisation and population growth require an expansion of transport and electricity infrastructure, especially in developing countries. By 2050, the global population is expected to increase to 9 billion people, 66% of which will be urban, compared with 54% in 2014. Demand for urban mobility is expected to nearly double between now and 2050, with most of this growth concentrated in developing countries (OECD/ITF, 2017). One in 8 people still live in extreme poverty, nearly 800 million suffer from hunger, 1.1 billion live without electricity, and water scarcity affects more than 2 billion (UN, 2016). Countries that are caught in a low-growth trap could use this opportunity to boost their growth in the short-term, capitalising on the current environment of low interest rates, or optimise the taxation-spending balance to increase infrastructure spending (see Chapter 4).

The importance of infrastructure quality for sustainable growth and well-being can be seen by looking at both access to basic services and at a measure of the quality of the underlying infrastructure (Figure 3.1). For example, while many high-income and middle-income countries boast near-universal access to electricity, in many cases the quality of electricity supply is mediocre, with important consequences for both economic activity and well-being.

Figure 3.1. **Quality of infrastructure and access to basic services in G20 countries, by income and growth groups**



Note: The growth groups are based on the 2010-15 average of GDP growth, population growth and gross capital formation as a share of GDP.

Source: Authors, based on WEF (2015) and World Bank (n.d.a.) (accessed on 28 February 2017).

StatLink http://dx.doi.org/10.1787/888933484204

The infrastructure investment gap

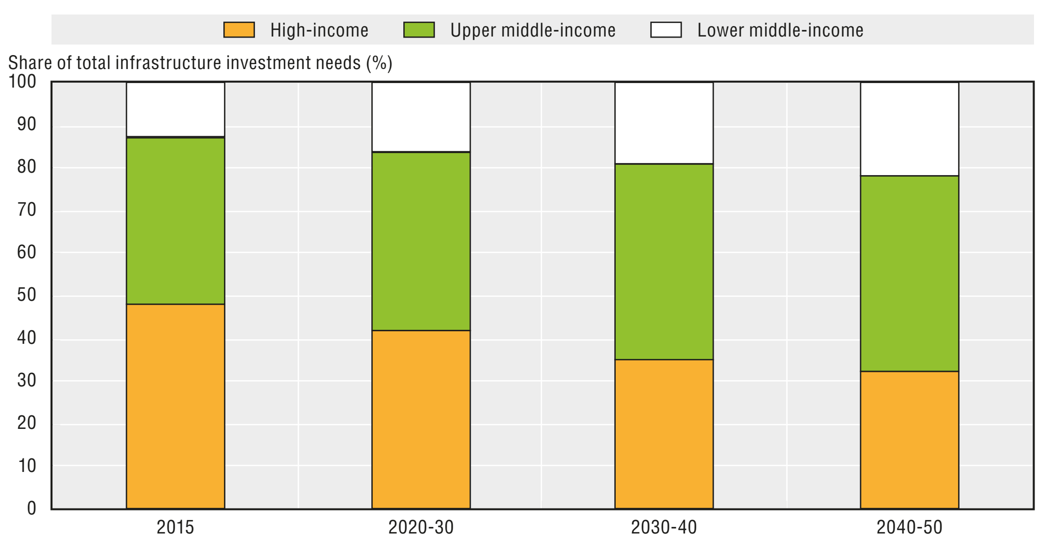
The OECD estimates that around USD 95 trillion of investments will be needed between 2016 and 2030 in energy, transport, water and telecommunications infrastructure to sustain growth, or around USD 6.3 trillion per year, even if governments take no further action on climate change (Table 3.1). This number is to be compared with current infrastructure spending of around USD 3.4 to USD 4.4 trillion (IEA, 2017; IEA, 2016b; Woetzel et al., 2016; Bhattacharya et al., 2016b). Middle-income countries are expected to represent around 60% to 70% of future infrastructure needs (Pardee Centre, n.d; NCE, 2016; Bhattacharya et al., 2016b) (Figure 3.2). The majority of infrastructure investments are required in transport and power, two critical sectors that are also at the heart of decarbonisation strategies (Figure 3.3). However, all infrastructure estimates need to be read with caution (Box 3.1).

Table 3.1. **Global estimates of infrastructure investment needs 2016-30, by sector (before taking into account climate considerations)**

USD 2015 trillion		Annual average	Cumulative
Energy supply	Power and Transmission & Distribution (T&D)	0.7	11.2
	Fossil fuel supply chain	1.0	14.3
Energy demand		0.4	6.6
Transport infrastructure	Road	2.1	31.8
	Rail	0.4	6.4
	Airports and ports	0.2	2.7
Water and sanitation		0.9	13.6
Telecoms		0.6	8.3
TOTAL		**6.3**	**94.9**

Sources: IEA (2017) for energy supply and demand; IEA (2016d) for road and rail infrastructure; OECD (2012) for airports and ports; McKinsey (Woetzel et al., 2016) for telecoms. The water and sanitation estimate is an average of estimates from: Booz Allen Hamilton (2007), McKinsey (Woetzel et al., 2016) and OECD (2006). See technical note on estimating infrastructure investment needs for further details on methodology (http://oe.cd/g20climatereport).

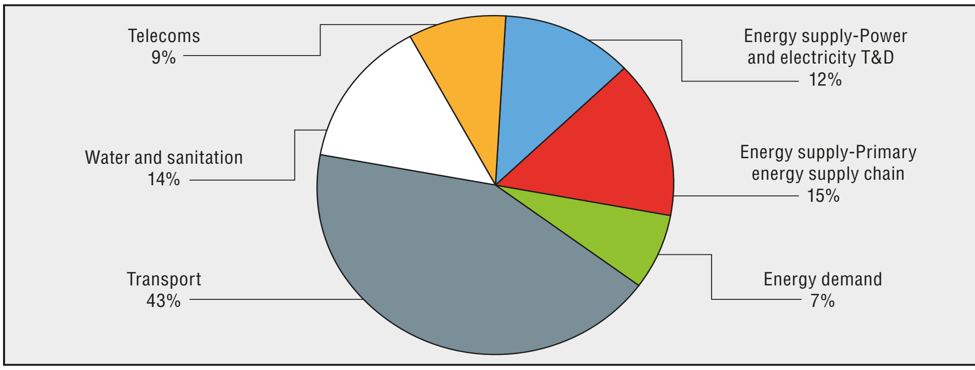
Figure 3.2. **Evolution of infrastructure investment needs by income groups in the G20**



Source: Pardee Center (n.d. accessed February 2017).

StatLink http://dx.doi.org/10.1787/888933484216

Figure 3.3. **Global investment needs by sector, 2016-30**



Source: As per Table 3.1.

StatLink http://dx.doi.org/10.1787/888933484229

Box 3.1. **The challenges of estimating infrastructure investment needs**[1]

There have been several attempts to provide estimates on infrastructure investment needs (WEF, 2013; NCE, 2014; Bhattacharya et al., 2016; Woetzel et al., 2016; Kennedy and Corfee, 2012). Each projection is highly uncertain as it combines several distinct sources, each with different underlying assumptions:

- Projections attempt to take as a starting point existing infrastructure investment, but there is a lack of comprehensive data on investments across countries, including G20 countries (AsDB, 2017, Bhattacharya et al., 2016b). There is a need for national and international agencies to gather more comprehensive, better quality data on infrastructure investment.
- Most infrastructure needs assessments are based on projected GDP growth and country-level elasticity of infrastructure spending to growth (Woetzel et al., 2016; NCE, 2016), which results in estimates that are highly dependent on GDP assumptions. Few studies are based on achieving minimum quantitative benchmarks for infrastructure stocks and services (such as those used by Pardee Center, 2014), which is more relevant in particular for low-income countries and in the context of the SDGs.
- Most infrastructure assessments are based on global models, but infrastructure needs and priorities depend on countries' specific circumstances – such as access to energy, quality of current infrastructure, growth rate and inequalities – and should be informed by country-specific long-term development strategies.
- Many assessments do not account for how infrastructure is managed and implemented. Some analysts suggest that better management of infrastructure could lower infrastructure investment needs (Woetzel et al., 2016).
- Many assessments do not integrate incremental investment needs for climate change adaptation and mitigation. When they do, they do not necessarily take a network approach, to account for the interdependency between infrastructure systems. For instance, decreased demand for energy reduces the capital requirements for new infrastructure in oil, gas and coal, potentially freeing up rail and port capacity (Kennedy and Corfee-Morlot, 2012).

The figures presented here offer an up-to-date estimate based on the sources listed in Table 3.1. The new estimate in this report is around USD 4.9 trillion per year for energy, transport, water and telecommunications infrastructure, reflecting a recent reevaluation of investment needed in transport (IEA, 2016d). This estimate is of a similar order of magnitude

Box 3.1. **The challenges of estimating infrastructure investment needs**[1] *(cont.)*

to figures presented in other analyses. The New Climate Economy (NCE) (2014) estimated that the world needed to invest USD 57 trillion (USD 3.8 billion per year) in infrastructure between 2014 and 2030, or around USD 96 trillion (USD 89 trillion in 2010 dollars) including primary energy generation and energy efficiency. More recent estimates by Bhattacharya et al. (2016b) anticipate larger needs: USD 75-86 trillion (or USD 5.4 trillion a year), excluding primary energy and energy efficiency – USD 1.6 trillion more per year than the NCE.[2] McKinsey (Woetzel et al., 2016) estimates cumulative needs of USD 49 trillion (or USD 3.3 trillion per year) for the period 2016-30 (Table 3.2). The Pardee Center (2014) estimates that annual spending in infrastructure will be on average USD 4.3 trillion per year between 2014 and 2050.

Table 3.2. Selected estimates of infrastructure investment needs, 2016-30 – annual averages in 2015 USD trillion per sector

	Energy supply					
	Power and T&D	Primary energy use supply chain	Energy demand/ efficiency	Transport	Water and sanitation	Telecoms
OECD (2017)	0.7	1.0	0.4	2.7	0.9	0.6
Bhattacharya et al. (2016b)	1.5	0.8	1.6	2.0	0.9	1.0
McKinsey (Woetzel et al., 2016)	1.0	not included	not included	1.2	0.5	0.6
NCE (2014)	0.7	0.9	1.7	1.0	1.5	0.5

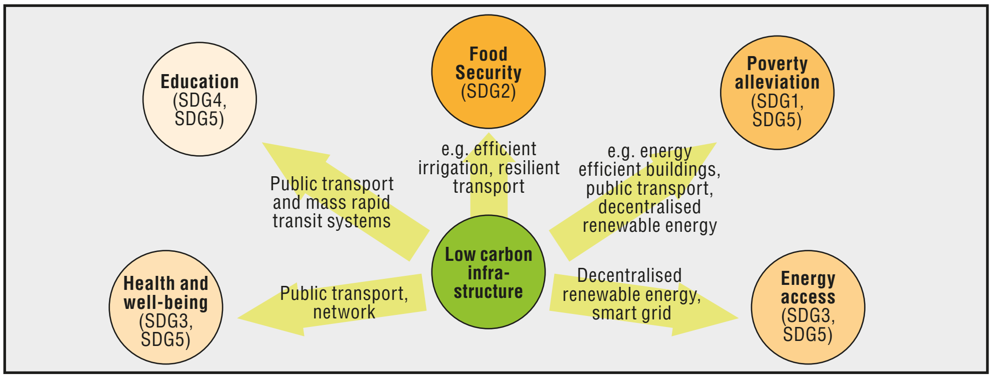
Note: See technical note on estimating infrastructure investment needs for further details (http://oe.cd/g20climatereport).
Sources: NCE, 2014; 2016; Bhattacharya et al., 2016b; Pardee Center, 2014; Woetzel et al., 2016.

Shifting infrastructure investment for low-emission, climate-resilient pathways

Low-emission, climate-resilient pathways will require an unprecedented transformation of our infrastructure system. Most existing energy and transport infrastructure was designed and built for a world of cheap and abundant fossil fuels, contributing to economic growth in many regions but also to GHG emissions. As a result, around 60% of GHG emissions are hard-wired into existing infrastructure (NCE, 2016; IPCC, 2014). In an effort to keep average global warming well below 2°C, the Paris Agreement stipulates that a “balance” between anthropogenic sources and sinks of GHGs must be reached by 2050-2100, so that there are zero net emissions to the atmosphere in the second half of the century (see Chapter 2). In many cases, it will be important to shift as much investment as possible towards zero-emission (rather than low-emission) options, given that some difficult-to-decarbonise sectors will still have residual emissions.

In addition to being responsible for more than 80% of energy-related CO_2 emissions (IEA, 2016a), G20 countries represent around two-thirds of global investment needs in infrastructure. This share is expected to raise to 75% of infrastructure needs between 2016 and 2030 (Pardee Center, n.d.). G20 country choices are critical to the world’s ability to mitigate climate change and will also dictate the resilience of G20 infrastucture to climate change impacts. The infrastructure required for the low-emission transition is also integral to meeting many of the SDGs beyond SDG13 on climate change (Figure 3.4).

Figure 3.4. **The links between low-carbon, climate-resilient infrastructure and the SDGs**



Infrastructure and technology shifts for low-emission pathways

Achieving low-emission, climate-resilient pathways requires strategies spanning infrastructure, technology development and innovation in the energy, land-use and agriculture sectors. This section examines the implications for infrastructure and technology of the shift to zero net emissions across these different categories (Table 3.3).

Table 3.3. **Examples of infrastructure and technologies needed for a low-emission transition**

	Strategies	Infrastructure needs		Technologies
Transport	Improve carbon intensity of vehicles Shift to more efficient transport modes Avoid carbon intensive mobility when possible	Passenger	Charging infrastructure for electric cars and fueling infrastructure for hydrogen cars Intelligent Transport Systems Smart grids Rail Mass rapid transit systems (light rail, metro, bus rapid transit lanes) Infrastructure for walking, cycling	Electric cars Advanced biofuels and biojet (algae) for air and maritime transport Hydrogen aircrafts Batteries
		Freight	Hinterland rail infrastructure	Electrification of trucks Advanced biofuels, hydrogen for shipping Investment in agriculture research (yields)
Energy	Decarbonise the power sector Electrification of end-uses Energy efficiency	Energy and power generation	Renewable energy (wind, solar, thermal energy, tidal, waves) Smart grids Infrastructure for CO_2 transport and storage	Energy storage (thermal cycle, power to gas, batteries) Tidal, thermal energy CCS (large-scale demonstration)
		Buildings	Retrofitting of the building stock Energy-efficient new build Heat supply	Zero energy or positive energy buildings Alternative material for steel and cement
Heavy industries	Energy efficiency in industrial processes Material efficiency Capture of emissions		Energy efficiency in industrial processes Infrastructure for CO2 transport and storage	CCS (large-scale demonstration of industrial CCS applications) Hydrogen in steel making
Land use	Improve carbon sequestration by land Minimise emissions from food production, including livestocks	Negative emissions	Infrastructure for CO_2 transport and storage	CCS Direct air capture and storage BECCS (deployment at commercial scale) Biochar Ocean liming
		Agriculture	Restoration of degraded grassland	Research on yields improvements Innovative agricultural practices to improve productivity

Source: Authors.

Infrastructure for low-emission energy and transport systems

Energy production and use accounts for around two-thirds of all anthropogenic GHG emissions, mostly in the form of CO_2 from the combustion of fossil fuels (IEA, 2017). Creating low-emission pathways requires radical changes in infrastructure, not only to reduce the carbon intensity of energy supply, but also to create less energy-intensive behaviours and to reduce energy use in transport, buildings and industry. The main elements of infrastructure-related changes needed to reshape energy supply and use are described here, with the main technological breakthroughs needed covered in Box 3.2.

Key to the energy transition is the decarbonisation of electricity, including phasing out inefficient coal-fired power plants and unabated coal, the widespread deployment of renewable energy sources, further development of nuclear power according to country choices, and potentially the development of negative emissions technologies (NETs) such as bio-energy with carbon capture and storage (BECCS) (IEA, 2017). Significant investments in smart grids will be needed to help manage demand and support increased penetration of intermittent renewable energy. On the demand side, reducing energy use in transport and buildings will be key.

Transport produces roughly 23% of global CO_2 emissions and is the fastest-growing source globally. Without further policy action, CO_2 emissions from transport could double by 2050 (OECD/ITF, 2017). Reducing emissions from transport is not only crucial for a low-carbon transition: it also reduces air pollution and congestion. The strategies necessary will depend on each country's circumstances, for example to what extent cities have already been developed around car ownership, and where opportunities exist to use urban planning to reduce the need for personal vehicles (OECD, 2015a). In general, ambitions will only be fulfilled with integrated policy action to:

- *avoid* unnecessary travel and reduce the demand for total motorised transport activity;
- promote the *shift* to low-emission and even zero transport modes; and
- *improve* the carbon intensity and energy efficiency of fuels and vehicle technologies. Significant advances have been made recently, notably in the electrification of transport via battery and fuel cells vehicles that are now on the market.

Building sector energy use was responsible for 9% of CO_2 emissions in 2013 in G20 countries. Increasing energy efficiency in buildings has not been sufficient to offset large increases in energy demand driven by the growth in population, energy-intensive appliances, and heating and cooling of buildings (IEA, 2016c). This is despite the availability of technologies that could lead to widespread decarbonisation of buildings through immediate widespread uptake. In developing and emerging economies, the building sector tends to be dominated by new construction and demolition of older buildings as cities expand. Integrating energy efficiency principles early in construction is therefore more important than retrofitting existing buildings. In mature economies, 75-90% of today's buildings will most likely still be in service by 2050. Many of these buildings are not built to the standards of today's energy efficiency codes and do not benefit from the latest energy-saving technologies; as a result, 30% of current buildings will need to be retrofitted by 2030 (IEA, 2017). Energy demand and efficiency of the appliances contained in buildings also has a major impact (Climate Policy Initiative, 2013). Managing policy decisions in tandem with investment decisions on heating, cooling, and power transmission and distribution infrastructure could enable additional cost reductions.

Box 3.2. **Which technological innovations are needed for a low-carbon economy?**

Many of the technologies needed to decarbonise the economy are known and available at a commercial scale, even though ongoing R&D will likely see further cost reductions: electric vehicles, renewable electricity generation and advanced building insulation techniques are all examples. However, to achieve pathways consistent with the Paris goals, many new technological breakthroughs will be required. Twenty-one technological innovation priorities were identified for this project that are crucial to achieving a low-carbon economy but have not yet been deployed at commercial scale and therefore still require significant R&D. Some key examples are described here.

Carbon capture and storage (CCS)

Current scenario projections rely heavily on CCS to meet emission targets. In the IEA scenario consistent with a 66% chance of reaching the Paris Agreement's 2°C goal, CCS contributes around 15% of emissions reductions by 2050 (IEA, 2017). In industry, it accounts for one-fourth of cumulative CO_2 emissions savings by 2050 relative to the New Policies Scenario. Furthermore, negative emissions technologies (NETs) such as bioenergy with CCS (BECCS) would benefit from the advancement of conventional CCS. While the components of carbon capture, transport, injection and storage have been demonstrated individually at commercial scale (Florin and Fennell, 2010), large-scale demonstration is an urgent priority to overcome the challenges of whole systems integration across the CCS chain (LCICG, 2014). The main research priorities are: (1) developing advanced adsorption and membrane processes; (2) advanced processes such as Ca-looping; and (3) improved modelling of CO_2 storage, including optimal injection scenarios and expected leakage (IEA, 2012; UKCCSRC, 2015).

The cost of CCS for power generation is estimated at USD 43-80/tCO_2 (IEA, 2012). CCS applied to industrial processes is less well developed and is generally more challenging, but has the potential to be cheaper than CCS for power generation. Each process and site is unique and will likely require bespoke equipment and plant design. Current cost estimates are USD 15-138/tCO_2 for cement and USD 51-64/tCO_2 for steel (Fennell et al., 2012). Research priorities for industrial CCS include: (1) improving heat and flow integration; (2) testing the impact of impurities on the capture process; and (3) developing novel sorbents optimised for industrial operating conditions.

Industrial sector (energy use and process emissions)

The industrial sector accounts for one-third of global emissions. Of this, steel, cement and chemicals together make up over 70% (IEA, 2010). Energy efficiency improvements will not be able to reduce industrial emissions as needed. The other options for achieving low (or zero) emissions from industrial processes are: switching from fossil fuels to biomass or hydrogen; electrification; and CCS. With the exception of biomass usage in certain applications, all these options are still in the concept phase. There is an urgent need to develop breakthrough processes (e.g. steel production based on hydrogen or electrolysis) that could result in a step-change in emissions reductions. Development of alternative building materials to steel and cement could reduce emissions from both industry and the built environment. Alternative cement chemistries (i.e. not based on limestone) could provide a low-carbon solution for cement, but extensive testing would be required to gain wide-scale acceptance in the construction industry.

Aviation sector

CO_2 emissions from aviation amounted to 700 MtCO_2 in 2013, or around 2% of global CO_2 emissions (Elgowainy et al., 2012). With demand expected to rise by around 5% per annum, emissions could be as high as 3 100 MtCO_2 by 2050 (ATAG, 2014). In the medium term, radical new aircraft designs (e.g. the "blended wing" concept) could improve fuel efficiency by 25% compared with the most efficient planes today (DfT, 2007). In the short term, options for low (or zero)

Box 3.2. **Which technological innovations are needed for a low-carbon economy?** *(cont.)*

carbon airplanes are extremely limited. Biofuels present the most viable alternative but are limited to those that meet industry standards and are interchangeable with conventional fuels. New engine designs that can cope with the low aromatics composition of biofuels could open the aviation sector up to cheaper biofuels supply options. Hydrogen-powered planes should not be ruled out. In 2016, the first four-seater hydrogen fuel-cell powered plane took flight (Pultarova, 2016). While this is promising, significant technical challenges need to be overcome for commercial-scale hydrogen powered planes to become a reality. In particular, the low energy density of hydrogen requires a large storage volume, which will require major design modification. A starting point for hydrogen in aviation may be for use during taxiing. EasyJet is exploring this idea (Carrington, 2016).

These alternative fuels for aviation, as well as other sectors, will rely on cost-effective and scaled-up supply chains. Researching and designing new plant strains optimised for biofuel production would increase crop yield and reduce the cost of biofuel supply. Other promising avenues for investigation include cellulosic biomass, algae and halophytes (Epstein, 2014). Hydrogen supply from electrolysis, which requires a large amount of electricity, could be superseded by new technologies such as photocatalytic water splitting (Hisatomi et al., 2014; Moniz et al., 2015) or microbial processes (Magnuson et al., 2009), reducing the amount of electricity required per unit of hydrogen produced.

Negative emission technologies (NETs)

There are five main NETs: direct air capture, the lime-soda process, augmented ocean disposal, biochar and bioenergy with CCS (BECCS), the best known. Cost estimates for NETs are USD 59-155/tCO_2e (Workman et al., 2011). With the exception of BECCS, all NETs are in a very early stage of technical development. BECCS relies on a sustainable source of biomass; given competing pressures for bioenergy across different sectors, it is unlikely that BECCS alone will be adequate. The main research priorities are: (1) developing novel sorbents to reduce the energy input for direct air-capture technologies and the soda/lime process; (2) optimising the design of pyrolysis plants for biochar production (3) integrated testing of CCS with 100% biomass-firing; (4) improving liquefaction processes for artificial trees; and (5) systematic studies of biochar effectiveness, focusing on repeatability and side-effects (Gurwick et al., 2013; Workman et al., 2011).

Electricity storage

Electricity storage is required to accommodate high levels of intermittent renewable generation. Beyond 2050, scenarios limiting global warming to 2°C have a share of generation from intermittent renewables greater than 50%. A rule of thumb is that for every GW of intermittent renewables, 1 GWh of storage is required (Budischak et al., 2013). The research priorities for electrical batteries include new cell chemistries emerging from the lithium-ion family, such as lithium-air (Grande et al., 2015) and lithium-sulphur (Fotouhi et al., 2016), or other metals such as sodium and magnesium (Erickson et al., 2015). These could improve power and charge density (Zhang, 2013), decreasing the cost per unit of energy stored. Improved manufacturing techniques and efficient management of battery packs could provide evolutionary cost and performance improvements. Capital costs of lithium-ion batteries of around USD 193-254 per kWh of storage capacity are possible (Darling et al., 2014) and new cell chemistries could offer further reductions to reach the USD 150/kWh thought to be the threshold for commercialisation of battery technologies for battery electric vehicles (Nykvist and Nilsson, 2015). Less mature electricity storage technologies, such as redox flow batteries, molten salt batteries, flywheels, and power-to-gas could also play an important role in balancing supply and demand over different timescales (from seconds to months), and different scales (distributed and centralised) (Brandon et al., 2016).

Source: Napp, T. (forthcoming).

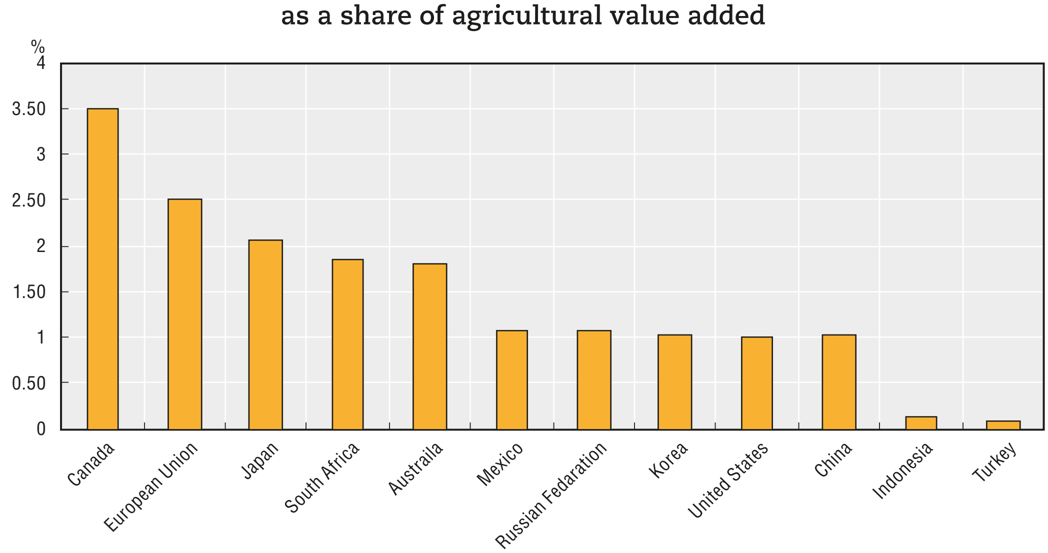
The importance of innovation in land use sectors

Chapter 2 highlighted the importance of agriculture, foresty and land use (AFOLU) for low-emission pathways, accounting for around 25% of global anthropogenic GHG emissions, mainly deforestation (9-10% of emissions) and agriculture (10-12%, mainly methane and nitrous dioxide) (IPCC, 2014). In some countries, proportions are much higher: land use and agriculture were responsible for 48% of emissions in Indonesia, 46% in Brazil, 31% in Argentina, and 27% in Australia (FAO, n.d.). By 2050, land will have to supply 60% more food than it does today to feed a growing population (Alexandratos and Bruinsma, 2012). It will have to do so in a way that does not further harm the climate. AFOLU sectors are expected to play a significant role in low-emission development pathways through carbon sequestration and sustainable approaches to managing land and livestock, and climate adaptation.

While crucial for low-emission pathways, AFOLU sectors differ from other sectors of the economy in the sense that infrastructure is not central to low-emission strategies (Box 3.3), at least in the short term. In the long term, infrastructure investments will be needed to increase resilience of agriculture (for example through access to on site renewable energy sources), to optimise the transport of produced goods, and to further develop ship and rail freight (Box 3.3).

Innovation is central to low-emission, climate-resilient land-use strategies. Although agricultural emissions of methane (CH_4) and nitrous oxide (N_2O) are notoriously difficult to reduce, technological innovation offers possible paths. This includes improving crop and livestock productivity (e.g. by developing crop varieties that are resilient to local hazards and that inhibit the production of nitrous oxides); more efficient fertiliser use; improved soil management; and practices aimed at reducing CH_4 emissions from ruminants, rice paddies and manure management. Better agricultural practices that increase the productivity of arable land in a sustainable manner would also help to halt and reverse deforestation and widespread land degradation, which is estimated to cost USD 100 billion per year (Delgado et al. 2015).

Figure 3.5. **Government spending on agricultural knowledge and innovation systems in 2012-14 in selected G20 countries, as a share of agricultural value added**



Note: a. Government spending on agricultural knowledge and innovation systems includes funding of agricultural research, agricultural education, training and extension services for farmers. b. Exchange rates used in the OECD Producer and Consumer Support Estimates database have been applied here: http://www.oecd.org/agriculture/agricultural-policies/producerandconsumersupportestimatesdatabase.htm. c. Data for other G20 countries are not available.

Source: OECD (2016b).

StatLink http://dx.doi.org/10.1787/888933484231

Agricultural innovation is not only about technological improvements but also about education, training and organisational improvements. Further investment in research and development and education is hence central to spur agricultural innovation that can improve sustainable productivity growth (Ignaciuk, 2015). Indeed, the level of technological development and innovation in agriculture has a direct impact on its capacity to produce adequate and sustainable supplies of food and feed (OECD, 2014). Given the importance of sustainable productivity growth for achieving ambitious mitigation targets, G20 countries can be encouraged to increase their spending in agricultural knowledge and innovation systems (Figure 3.5).

Box 3.3. **Investing in innovation and infrastructure for resilient agriculture**

Ensuring access to a secure water supply will be one of the main challenges of the land use sector – particularly agriculture – in the years to come. Climate change is expected to reduce crop yields in some areas. Coupled with increased demand for food from a growing population with increasingly rich diets, this will impose serious strains on agricultural systems, threatening food security in the most vulnerable countries.

Strategies to adapt agricultural systems are varied. Much can already be achieved by increasing the sector's reliance on on-site renewable energy sources, as well as optimising the transport of produced goods by shrinking the distance food is transported, and developing ship and rail freight. Technology also has a considerable role to play, via such measures as:

- developing new crop varieties that are drought-resistant and better adapted to higher temperatures; and
- improving water efficiency via the widespread dissemination of pressurised irrigation systems (e.g. sprinklers and drip irrigation), which decrease water demand while increasing the efficiency of water use.

Significant investment in R&D will be required to increase the resilience of agricultural systems to climate change. In OECD member countries, annual adaptation costs in agricultural R&D and in improved irrigation technology are estimated at USD 16-20 billion by 2050. In the short term, most of this investment is likely to come from public sources, although by 2050 the private sector is likely to invest more in this area than the public sector (Ignaciuk and Mason-D'Croz, 2014). Governments could facilitate private investment by lowering investment barriers that impede R&D, ensuring that private knowledge is disseminated, and encouraging public-private partnerships for R&D, where appropriate (Ignaciuk, 2015).

Incremental investment needs: mitigation

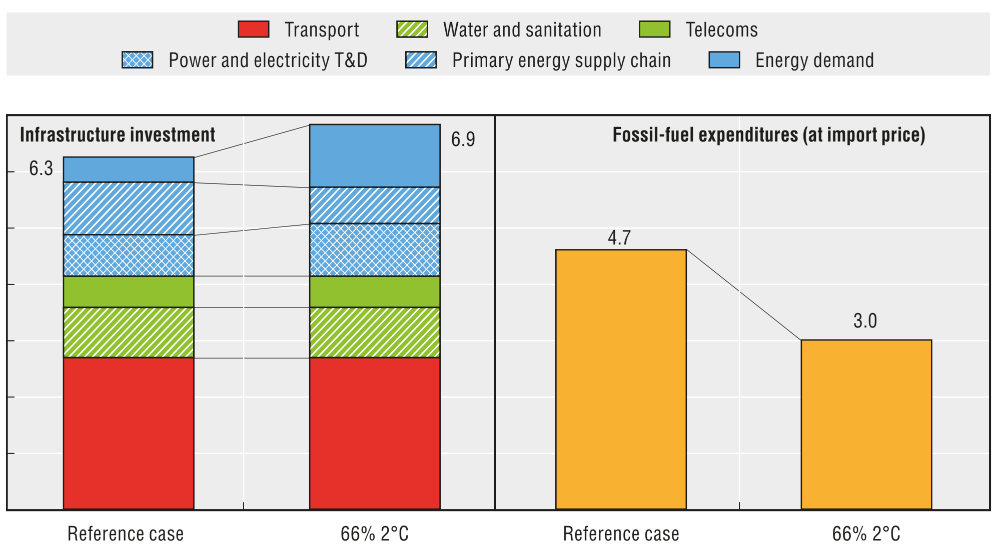
Assessment of the incremental capital requirements for putting the world on track to meet the mitigation objectives of the Paris Agreement depends on a number of factors, including the interpretation of the target (e.g. well below 2°C or efforts towards 1.5°C, likelihood of reaching the target); assumptions concerning decarbonisation strategies chosen (e.g. with or without nuclear, accounting or not for behavioural changes such as modal shifts in transport); and assumptions made on several factors such as the evolution of GDP, population, and technology costs.[3]

Consistent with the global pathways analysis in Chapter 2, this section takes as its core the IEA scenario consistent with a 66% likelihood of keeping the global average surface temperature increase to below 2°C throughout the century (IEA 66% 2°C scenario, IEA 2017).

The OECD estimates that around USD 103 trillion of cumulative investment between 2016 and 2030 would be required for the IEA 66% 2°C scenario, or 10% more than in a scenario where no further action is taken to mitigate climate change. The major shift of energy supply investments towards low-emission alternatives and significant scaling-up of demand-side investments for energy efficiency assumed by the scenario would require 29% more investment in the energy sector alone (IEA, 2017). Annual investment needs in transport, water and sanitation, telecommunications and energy supply and demand would be around USD 6.9 trillion over the next 15 years, versus USD 6.3 trillion a year with no further action (Figure 3.6, left-hand panel).

The incremental capital cost of shifting investments for the IEA 66% 2°C scenario is therefore significant, but not prohibitive; furthermore, incremental costs would be offset by fuel savings of up to USD 1.7 trillion per year through 2030 (Figure 3.6, right-hand panel). Factoring in modal shifts in transport could also lower overall investment needs for low-emission pathways, due to reduction in vehicle ownership and less investment needed in parking space (IEA, 2016d). Finally, provided low-emission infrastructure investment is pursued in an integrated way with climate-consistent, growth-enhancing policies, it could form an integral part of a new growth model for low-carbon growth, offsetting incremental costs entirely (Chapter 4).

Figure 3.6. **Global annual infrastructure investment needs for a 66% scenario 2°C, and fuel savings, 2016-30, USD 2015 trillion**



Notes: Reference case assumes no further action by governments to mitigate climate change.

Sources: IEA (2017) and IEA (2016a) for energy supply and demand; IEA (2016d) for road and rail infrastructure; OECD (2012) for airports and ports; McKinsey (Woetzel et al., 2016) for telecommunications. The water and sanitation estimate is an average of estimates from: Booz Allen Hamilton (2007), McKinsey (Woetzel et al., 2016) and OECD (2006). See technical note on estimate of infrastructure investment needs for further details on methodology (http://oe.cd/g20climatereport).

StatLink http://dx.doi.org/10.1787/888933484243

The global infrastructure investment needs estimate presented here is higher than in previous exercises, partly because many past estimates were based on a less ambitious scenario with a lower chance of limiting warming to below 2°C. NCE (2016) and Kennedy and Corfee-Morlot (2012), for example, estimated that incremental capital costs could increase by as little as 5% compared to a business as usual scenario in a low-emissions future. The impact on investment needs of increasing the level of ambition is not just incremental and linear: it implies a radical reorientation of investments and measures to decarbonise sectors that are harder and more expensive to decarbonise (transport, aviation, industry). For instance, cumulative global investments increase by 13% in the IEA 66% 2°C scenario compared with a scenario with a 50% chance of meeting 2°C, mainly due to increased investment in low-emission electricity supply and end uses (IEA, 2017).

There are many uncertainties associated with those estimates. Further research is required to understand the impact of the digitalisation of energy on telecommunication infrastructure, for example. Deployment of BECCS may generate significant investments in CO_2 pipelines (Chapter 2). There are also many remaining uncertainties on the impact of a low carbon future on future demand in infrastructure beyond energy. Between 2010 and 2015, fossil fuels represented between 11% and 18% of the value of international trade in goods (UN, n.d.). Fossil fuels accounted for an average of 42% of total maritime traded volumes between 2011 and 2015 (UNCTAD, 2016). In the long term, a world less reliant on fossil fuels is likely to require fewer port capacities, oil and gas tankers, and hinterland railways to transport coal (Kennedy and Corfee-Morlot, 2012). Specific country contexts will also influence investment needs. Encouraging more efficient transport modes from the outset in developing and emerging economies where infrastructure continues to be built could generate significant savings, reducing the need for road and parking spaces, which in many non-OECD countries are more costly than the additional investments required in public transport infrastructure (IEA, 2016d).

Box 3.4. **Investment needs for low-emission urban mobility**

Cities have a major role to play in strategies to decarbonise transport (see Chapter 2). It is essential to integrate transport and land-use planning to reduce overall demand and facilitate the shift from individual cars to mass transit systems. The International Transport Forum undertook a modelling exercise to assess transport investment needs in G20 countries between 2015 and 2050 under three different scenarios for urban development (see OECD/ITF (2017) for more details) (Figure 3.7).

In the baseline scenario (BASE), no additional measures to reduce travel demand and CO_2 emissions are implemented. The combined effects of urban extension, population and income growth will result in a surge in motorised mobility. Road traffic – the sum of car-km and motorcycle-km – will increase globally by 91%. Most of the increase comes from G20 countries, with 7 600 billion additional vehicle-km out of a total of 11 100 billion. In the G20, this increases CO_2 emissions by 10%.

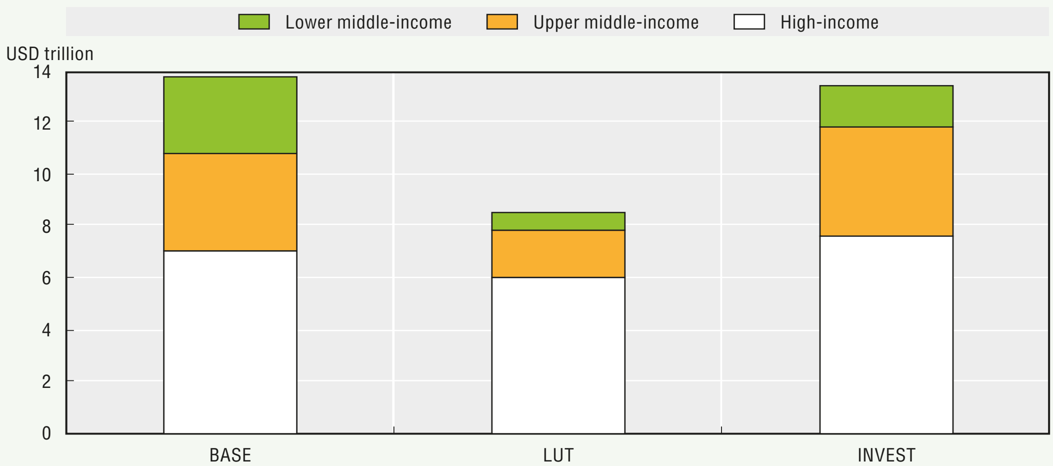
In the Integrated land-use and transport planning scenario (LUT), stringent policies targeting land-use planning, development of public transport and restriction of car use significantly mitigate CO_2 emissions. In G20 countries, transport emissions decrease by 34%.

In the strong investment scenario (INVEST), budgetary constraints on transit infrastructure are removed, increasing investment in mass transit infrastructure – urban rail, underground and tramways – especially in middle-income countries. This leads to a decrease of 50% in CO2 emissions.

Overall, aggregate infrastructure investment needs are smaller in the transit-oriented scenarios (USD 9 trillion in LUT and USD 13 trillion in INVEST) than in the baseline (USD 14 trillion). However, the results differ by income groups. High-income economies need to frontload urban transport investment towards light rail systems in the next 10 years. Middle-income countries can significantly decrease overall investment needs by 2050 by shifting investments in the next 10 years to rail.

Box 3.4. **Investment needs for low-emission urban mobility** *(cont.)*

Figure 3.7. **Investment in urban infrastructure in G20 countries, 2016-50, road and rail – ITF projection**



Source: Based on ITF data (accessed on 28 February 2017).

StatLink http://dx.doi.org/10.1787/888933484251

Incremental investment needs: adaptation

Estimates of the additional funding required for infrastructure adaptation depend on specific definitions of what constitutes "infrastructure adaptation", including which sectors are included (Box 3.5). In practice, costs are very context-specific, adding to the challenge.

Box 3.5. **Defining adaptation investments**

Adaptation investments can be considered across three areas:

Adaptation investments that create an enabling environment, such as investing in climate information, awareness raising and capacity building, and adapting governance systems to better account for the projected changes and deep uncertainty regarding climate change. If private stakeholders are sufficiently aware of climate risks, some adaptation investments make economic sense without public support.

Adaptation investments that "climate proof" infrastructure, reducing the exposure or vulnerability of an infrastructure asset or network, whether from the outset or as part of a retrofitting process. Such investment can take the form of engineering work with clearly identifiable additional costs, such as building a bridge higher than would otherwise be the case or building to higher design standards. It can also mean considering reduced exposure when siting or designing, often without incurring additional costs, for example siting back-up power generators to avoid them being flooded or modifying operational routines. It can also consist of pursuing a different approach to provide the same service, for example expanding green spaces to absorb rainfall in urban areas, instead of investing in larger drainage pipes.

Adaptation investments that fill gaps in infrastructure provision, particularly in developing countries, where infrastructure can be insufficient even for addressing current climate challenges.

Source: Agrawala and Fankhauser (2008).

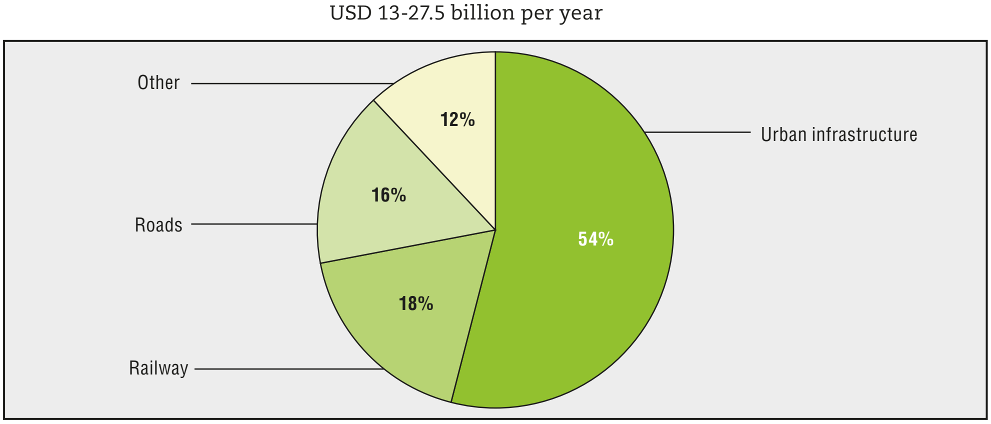
Several estimates of the global costs of adaptation feature a category on infrastructure adaptation. These tend to estimate the costs of "climate proofing" infrastructure by applying an adaptation cost mark-up to future investment plans to take account of future climate change. Such investments are estimated to be small compared with other factors that may influence the future costs of infrastructure. The cost of adapting infrastructure has been estimated at no more than 1-2% of the total cost of providing that infrastructure (Hughes, Chinowsky and Strzepek, 2010).

Other estimates take into account adaptation investments that fill gaps in infrastructure provision. Below are three recent estimates:

- The UNFCCC (2007) estimated that by 2030, the world would be spending USD 8–130 billion more each year on *new* infrastructure than would otherwise be needed in response to impacts associated with climate change, with two-thirds of the investment in OECD countries. This estimate excludes operating and maintenance costs, as well as the costs of adapting *existing* infrastructure, and any additional investment needed in water supply infrastructure (USD 11 billion, 85% of which will be needed in non-Annex 1 Parties) or housing.
- The UNFCCC estimates were criticised for failing to account for the infrastructure deficit in low and middle-income countries (LMICs), the investments in governance and technical capacity needed to maintain infrastructure in those countries, as well as the "residual" losses that cannot be prevented even with adaptation. With these elements taken into account, adaptation infrastructure investments in LMICs are eight times higher than the high-bound UNFCCC estimate (Parry et al. 2009.).
- Infrastructure accounts for a significant share of the USD 70-100 billion in annual global adaptation costs, according to a 2010 World Bank study on the costs between 2010 and 2050 of adapting to an approximately 2°C warmer world. Infrastructure adaptation is estimated to require USD 13-27.5 billion per year, depending on wetter or drier climate scenarios (Figure 3.8). Urban infrastructure (drainage, public buildings) accounts for over half of these costs, followed by railways (18%) and roads (16%), with costs highest in East and South Asia. This amount does not account for coastal zone adaptation, water supply or flood protection.

Figure 3.8. **World Bank estimates of global adaptation investment needs 2010-50**

USD 13-27.5 billion per year



Note: The estimate provided above does not account for adaptation in coastal zone adaptation, water supply or flood protection.

Source: World Bank (2010).

StatLink http://dx.doi.org/10.1787/888933484263

A transition is under way, but not at the required pace

The estimated global carbon budget consistent with a 66% likelihood of limiting global warming to below 2°C (described in Chapter 2) equates to 15 to 30 years of fossil fuel-related CO_2 emissions at current rates. Given the slow rate of capital stock turnover (Table 3.4), the infrastructure investment choices countries make over the next 15 years will be pivotal in determining the extent of global climate change. If governments continue to invest in fossil-fuel infrastructure, they risk locking in even higher levels of GHG emissions for decades to come, and they will enhance the risk of stranded assets. Long operational lives also make infrastructure vulnerable to the impacts of climate change in the coming decades. Overall, unless global emissions peak by around 2030 and fall to zero by 2100, serious climatic disruption could draw up to 720 million people back into extreme poverty (Granoff et al., 2015).

Information on infrastructure projects is not always complete or available to the level of detail required to allow meaningful analyses on progress in shifting investment in line with the Paris Agreement's goals. Energy is the only sector where information is more complete, as surveys and commercial databases track information on power plant capacity announced, at pre-construction stage, under construction, cancelled or in operation. This section therefore focuses on the energy sector as an indicative assessment of progress in aligning infrastructure investment plans for the transition, using the IEA 66% 2°C scenario as a benchmark.

Table 3.4. **Typical lifespans of selected infrastructure and equipment**

	Lifespan
Water infrastructure (dams, reservoirs, sanitation facilities)	30-200 yr
Transportation (port, bridges)	30-200 yr
Buildings, housing (insulation, windows, buildings)	30-150 yr
Power plants (coal-fired, gas-fired, nuclear)	20-60 yr
Cars	15-20 yr
Building appliances	10-20 yr
Industrial boiler	10-30 yr
Cities, urbanisms, land use planning	> 100 yr

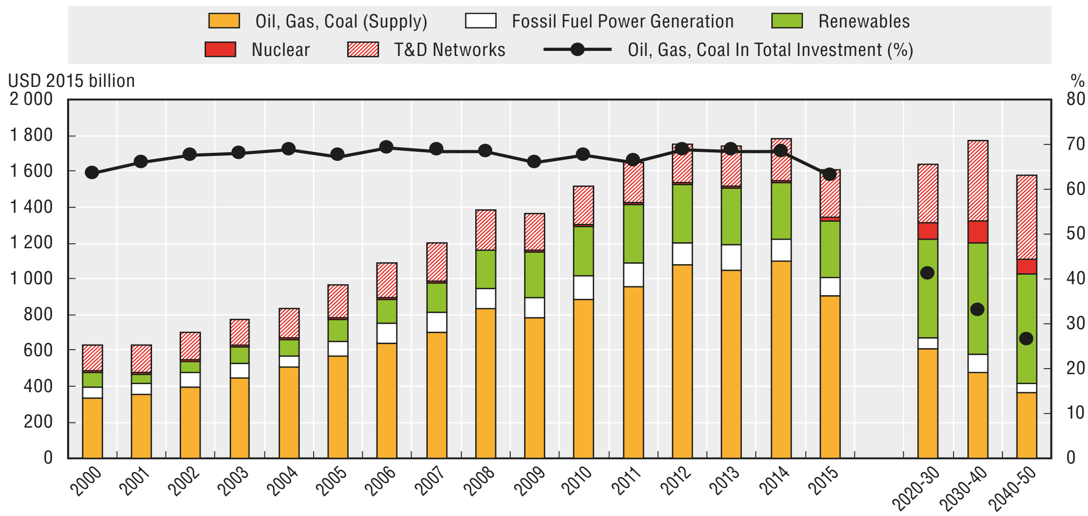
Source: Corfee-Morlot et al. (2012).

Investment is shifting towards cleaner infrastructure – but slowly

Fossil fuels have held the lion's share of energy supply investment in G20 countries. Fossil fuels continued to represent 63% of total supply-side investments, or USD 1 trillion in 2015. This share needs to drop to 26% by 2050 to be consistent with the IEA 66% 2°C scenario (Figure 3.9).

The transition is under way, however, with investment flows slowly shifting from fossil fuels to low-emission technologies in particular sectors. In power generation, G20 countries invested USD 290 billion in renewable energies in 2015, three times more than in 2000. Capacity investments have increased for wind, solar and hydropower generation in particular (IEA, 2016b). Since 2011, these technologies have captured approximately 40% of total annual investments in power generation (IEA, 2016b). This increase in total renewables capacity investment is even more impressive given that the cost of production of the technologies has decreased in the past few years: since the end of 2009, solar PV module prices have fallen by around 80% and wind turbine prices by 30-40% (IEA, 2017).

Figure 3.9. **G20 investment in energy supply 2000-15, and investment needs in the 66% 2°C scenario**

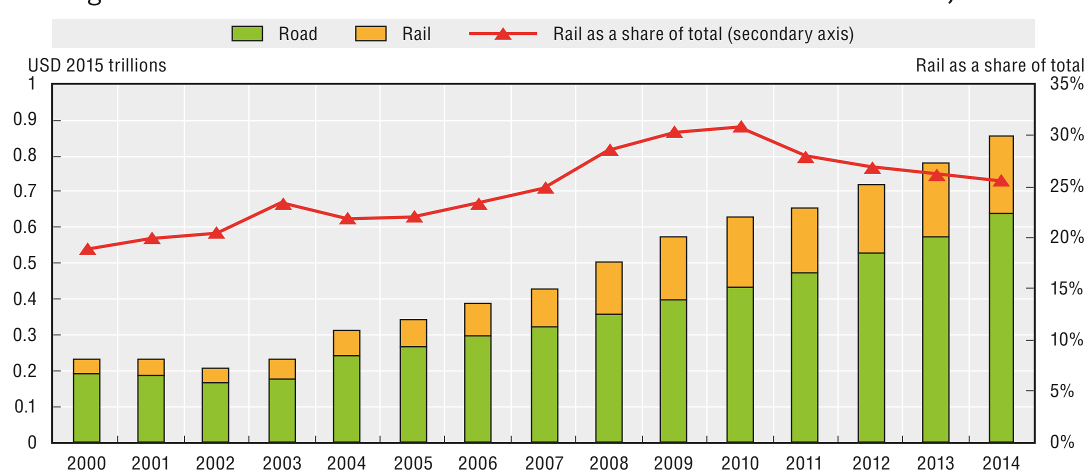


Sources: IEA, 2017; IEA, 2016b.

StatLink http://dx.doi.org/10.1787/888933484273

In the transport sector, most of the investment in G20 countries has targeted road transport since 2000, but the share of rail infrastructure investment – important to help promote the shift from emissions-intensive road transport – has been growing steadily, from 20% in 2000 to 26% in 2014, with a peak at 31% in 2010 (Figure 3.10). From a low of USD 250 billion in 2003, investment has more than doubled in size to reach USD 650 billion in 2014 (OECD/ITF, 2017). Investment in rail needs to increase significantly in the coming years to help fully decarbonise the economy.

Figure 3.10. **Road and rail infrastructure investment in G20 countries, 2000-14**



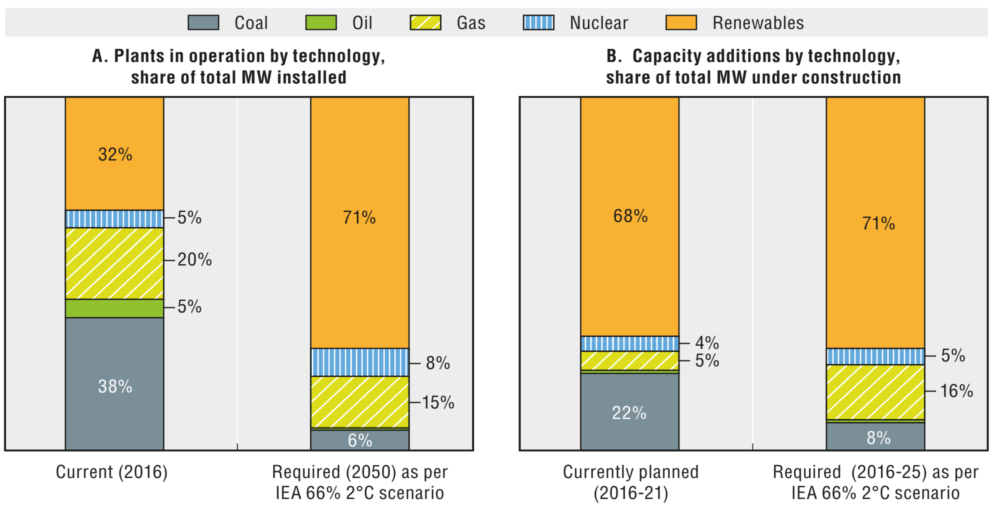
Source: OECD/ITF, 2017.

StatLink http://dx.doi.org/10.1787/888933484286

Investment plans are not yet aligned with the Paris Agreement's objectives

How, then, do current investment patterns and national energy sector infrastructure plans match up with the trajectory needed to achieve Paris objectives? In the power sector, the current capacity mix in G20 countries is still far from that required by the IEA 2050 scenario (Figure 3.11, left-hand panel). However, the plants under construction and planned for the next five years paint a different picture. The right-hand panel of Figure 3.11 compares this pipeline with required additions up to 2025 in the IEA 66% 2˚C scenario. The share of zero-carbon capacity additions is close to that required under the scenario (72% renewables and nuclear, versus 76% required). Solar and wind represent 84% of renewable generation capacity under construction, versus 36% for the plants in operation (Figure 3.12). However, the share of coal is much greater than the required level (22% of planned additions, versus 8% required). So, across the G20, the real challenge facing the power sector is accelerating the phase-out of coal-fired power generation.

Figure 3.11. **Current capacity and current pipeline of power plants relative to those required in a 66% 2°C scenario**

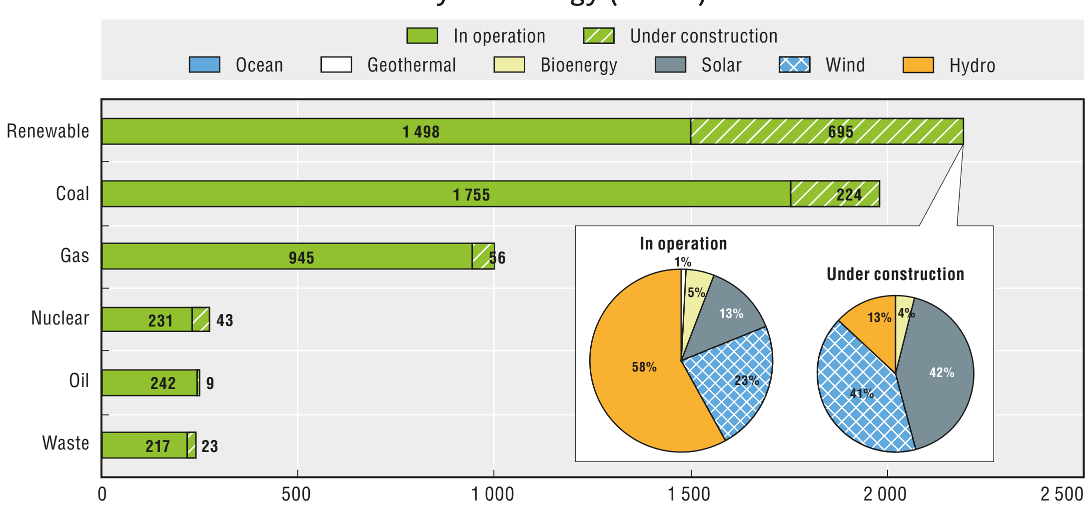


Note: Results are presented as share of total gigawatts and refer to power generation in operation in G20 countries in 2016, the energy mix in 2050 in the IEA 2°C 66% scenario, capacity additions in G20 countries for the period 2015-21, and global capacity additions in the IEA 2°C 66% scenario in the period 2016-25.

Source: Authors' analysis from *i)* Platts WEPP (2017) for oil and gas under construction; *ii)* the Global Coal Plant Tracker (2017) for coal under construction; *iii)* IAEA (2016) for nuclear under construction; *iv)* IEA (2016c) for renewable energy under construction; and *v)* IEA (2017) for capacity additions in the IEA 2°C 66% scenario.

StatLink http://dx.doi.org/10.1787/888933484293

Figure 3.12. **Power plants in operation and under construction in G20 countries, by technology (in GW)**



Source: Authors' analysis from *i)* Platts WEPP (2017) for oil and gas under construction (accessed March 2017); *ii)* the Global Coal Plant Tracker (2017) (accessed on 28 February 2017) for coal under construction; *iii)* IAEA (2016) for nuclear under construction (November 2016); and *iv)* IEA (2016c) for renewable energy under construction.

StatLink http://dx.doi.org/10.1787/888933484305

The level of coal plants in the pipeline is high despite recent falls in global capacity under development, mainly due to shifting policies and economic conditions in China and India – which account for 86% of coal power built globally between 2006 and 2016 – together with a reduction in overall power demand (Box 3.6). Pre-construction activity decreased by 48% from January 2016 to January 2017. Construction starts dropped 62%, and ongoing construction decreased by 19%. Coal plant retirements are taking place at an unprecedented pace, with 64 GW of retirements in the past two years, mainly in the European Union and the United States (Shearer et al., 2017). Nevertheless, the proportion of overall G20 capacity investment that is coal based could increase in the future, as 416 GW of coal plants are in pre-construction, and 543 GW are "on hold" (Figure 3.13).[4] Considerable further efforts are therefore needed. These efforts will not only be domestic. G20 economies also influence the type of infrastructure that is built outside of their borders, and especially in developing countries through development finance and export credits (Box 3.7)

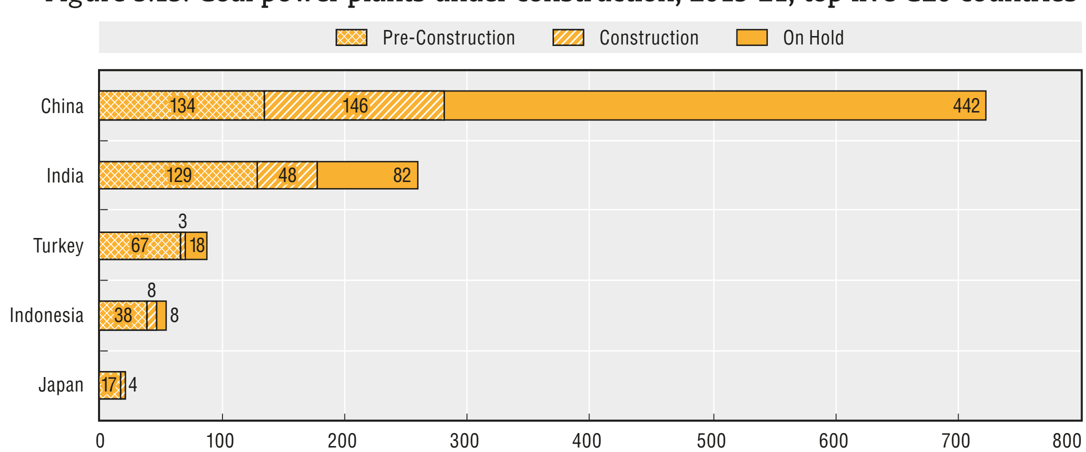
Box 3.6. **Recent reductions of the coal project pipelines in China and India**

In China, over 300 GW of projects in various stages of development were put on hold in 2016 until after the 13th Five Year Plan (2016-20), including 55 GW of projects that were already under construction. According to a survey by Greenpeace, the amount of new coal power capacity authorised for construction in 2016 in China was 22 GW, a decline of 85% from the 142 GW authorised in 2015.

In India, the draft National Energy Plan, released in December 2016, states that no further coal power capacity beyond that currently under construction will be needed until at least 2027; but there is already 177 GW in the pipeline before that date. Moreover, India is in the midst of a solar power revolution, with bids as low as Rs 2.97 (USD 0.044) per kilowatt-hour, and government proposals to install 215 GW of renewables (biomass, small hydro, wind, distributed solar PV, and utility scale solar PV) by 2027. Although some policy and financial challenges need to be addressed to reach the ambitious goals set by the government, the combination of the current low capacity utilisation rate of several coal power plants and the declining cost of renewables has caused many financial backers of coal projects to withdraw support. Construction activity is now on hold for 31 coal plant units at 13 sites totalling 12 725 MW of capacity, mainly due to frozen financing.

Source: Extract from Shearer et al. (2017).

Figure 3.13. **Coal power plants under construction, 2015-21, top five G20 countries**



Source: Authors' analysis based on the Global Coal Plant Tracker (2017) (accessed on 5 April 2017).

StatLink http://dx.doi.org/10.1787/888933484310

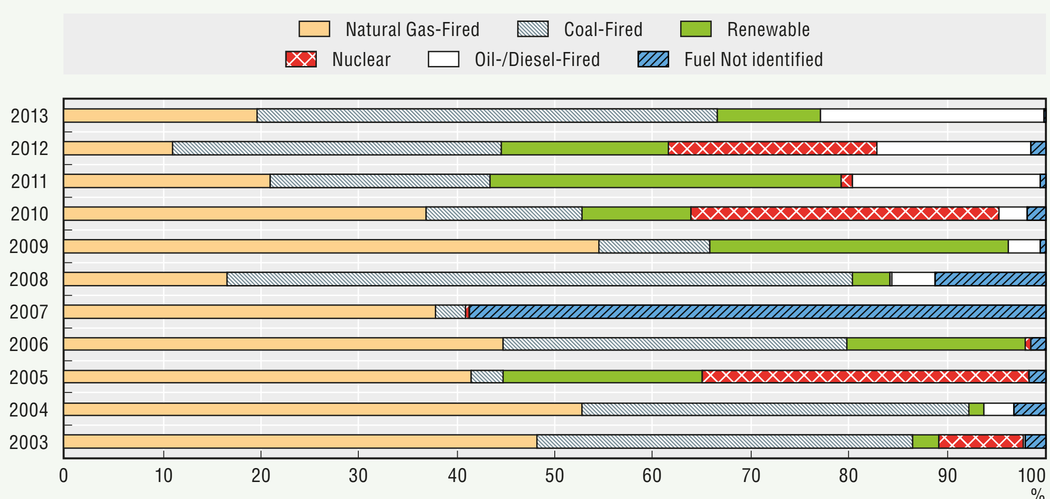
Box 3.7. **Aligning ODA and export credits for infrastructure investment with the Paris Agreement's objectives**

The G20 includes the biggest aid providers globally – roughly 77% of ODA and ODA-like flows come from G20 countries, according to the OECD-DAC statistical system – and while aid supports only a small share of infrastructure investment overall, it plays a critical role in low-income countries where it is difficult to mobilise domestic and external finance. Export credits – commercially motivated support linked to a country's trade strategy – also play an important role in financing infrastructure. For example, 20% of external finance for infrastructure projects in Sub-Saharan Africa is provided by China EXIM Bank alone (Gutman, Sy and Chattopadhyay, 2015).

An analysis of export credits in support of power generation from G20 countries that report to the OECD shows that the overwhelming majority of these credits supported fossil fuel technologies over the last decade (Figure 3.14). Export credits provided by G20 countries for coal power generation specifically amounted to USD 13.1 billion. Most signatories to the OECD's Arrangement on Export Credits have agreed to begin limiting export credits related to coal.

Figure 3.14. **Official export credits for power generation projects**

(Share per sector, G20 members reporting to the OECD Working Party on Export Credits and Credit Guarantees)



Note: G20 countries that report to the export credit committee are Canada, France, Germany, Italy, Japan, Republic of Korea, the United Kingdom and the United States.

Source: OECD (2015a).

StatLink http://dx.doi.org/10.1787/888933484324

Minimising the risk of stranded assets

Limiting global warming in accordance with the Paris Agreement will lead to some infrastructure being replaced before the end of its economic life, especially in energy supply and demand activities, as low-GHG solutions replace more GHG-intensive ones. The longer infrastructure investment plans are misaligned with the agreement's climate goals, the more extensive the value of the assets at stake. Locking in long-lived assets that risk later being economically stranded when policy constraints finally catch up will lead to higher costs if the global carbon budget is still to be met, and is sub-optimal from a global welfare perspective.[5]

Stranded assets are a common feature of market economies that spur reallocation of capital as some firms are outcompeted by others (Caldecott et al., 2017). A range of approaches has been used to define and quantify the climate-related risk for assets (Box 3.8). Similar assets may also face different financial risks depending on their contribution to their country's emission profile, making the identification of the exact magnitude of assets at risk more challenging. A natural gas power plant, for example, can play a positive role if it replaces low-efficiency coal or balances variable sources of power generation, or a negative role if it slows the penetration of renewables.

Box 3.8. **Climate-related risks for assets: clarifying the terms of the discussion**

Many different definitions have been used in the debate on the impact of climate policy and climate change on assets.

- **Stranded assets:** Assets whose investment cannot be fully recouped as the result of climate policy (e.g. a coal power plant closing before it has recouped investment as its electricity is no longer competitive, whether because of a carbon price, other forms of support to low-carbon generation, or on pure financial grounds). More precisely, if the revenues of an asset are lower than its capital expenditure minus operating costs, the difference is the estimate of the stranded asset.
- **Assets at risk under climate change:** Infrastructure at risk of being destroyed or made unusable as the result of local climate changes (flooding, sea-level rise, typhoons, droughts). Dietz et al. (2016) provide a first estimate of value at risk, estimated at 1.8% of global financial assets in their central estimate (USD 2.5 trillion), rising to 16.9% in a 99% percentile scenario (USD 24 trillion).
- **Foregone revenues:** Revenues lost as lower volumes of fossil fuels are sold, and sold at a lower price than would otherwise be the case without climate mitigation policies (also known as the "carbon bubble"). IEA argues that the foregone revenues can be larger than stranded assets as the former include profits, even if these are discounted.
- **Capital value loss:** The capital value that a company loses as its activity is impaired by climate policy (and possibly climate change damages), as used by IRENA for its upstream fossil fuel estimates of stranded assets (IRENA, 2017b). There is much overlap between foregone revenues and the capital value of an energy company, although much depends on how the company is managed, and how quickly it can diversify its portfolio (e.g. a company that produces oil exclusively versus an oil and gas company with a renewable energy branch and ownership in electricity distribution).
- **Unburnable carbon:** Fossil fuel resources that are not used due to climate mitigation policies, but that would be burned if there were no constraint on emissions, usually expressed in energy amounts (Carbon Tracker Initiative, 2013).

IEA (2017) and IRENA (2017a) represent the latest estimates of energy-related assets at risk; both use the notion of stranded assets, although their metholodgy, sectoral coverage and assumptions about the future energy mix differ. Assuming an orderly transition to meet the Paris Agreement objectives, the IEA 66% 2°C scenario estimates stranded assets at USD 852 billion between 2014 and 2050, distributed as follows:

- USD 320 billion for power (96% of which are coal-fired power plants), with about half of the stranded assets occurring before 2030.

- USD 532 billion for production facilities, including coal mines, oil and gas wells and processing plants, that fail to recover their capital investment as a result of climate policy (USD 120 billion for gas, USD 400 billion for oil and USD 12 billion for coal).

A less orderly transition – for example, a delay followed by abrupt action – is likely to have more deleterious effects. The IEA considers a "disjointed transition case", in which climate policy would change abruptly in 2025, shifting from weaker action to a more ambitious trajectory, allowing the world to stay within the carbon budget of the 66% 2°C scenario. This would mean a change in investors' and market expectations, with investments previously committed to fossil fuel-based production that would eventually be stranded following the change in policy. Stranded assets would then amount to USD 2.1 trillion, with the brunt of the additional assets in oil (USD 1 trillion) and gas (USD 300 billion). The "delayed action" scenario in Chapter 4 builds on these numbers.

IRENA provides a different set of estimates of asset risks based on a renewable energy-driven low-carbon transition scenario, REmap (IRENA, 2017a). In terms of sectoral coverage, IRENA differs from the IEA in including heavy industry and buildings, in addition to oil and gas.[6] Among other differences, while the same emission budget as the IEA is used, IRENA projects renewables to provide 65% of total primary energy by 2050, against 47% for the IEA scenario.[7] Results for the delayed action case are indicated in parentheses, confirming the much higher financial impact of an abrupt adjustment in mitigation policy:

- The capital value loss for the oil, gas and coal sector is estimated at USD 3.8 trillion (USD 7 trillion in a Delayed Policy Action case).
- Stranded assets in power generation are estimated at USD 200-300 billion for a low assumption of plants economic lifetimes and USD 1.2 trillion with longer lifetimes (USD 1.9 trillion in a Delayed Policy Action case).
- Stranded assets in industry are estimated at USD 220 billion (USD 740 billion in the Delayed Policy Action case).

A combination of IEA and IRENA estimates indicate that stranded assets could amount to USD 1.06 trillion for the energy supply and industry sectors – using IRENA's low range for industrial assets economic lifetime – a number that would nearly triple under a delayed action scenario. These amounts are significant for sectors at stake. However, they appear manageable when compared with the global infrastructure investment needs over the same period to 2050 – i.e. USD 244 trillion, particularly if exits are well planned and impacts on the work force are mitigated (Chapter 6).

Possible ripple effects through the financial system also need to be taken into account. Stranded assets can be viewed as the primary effect of what may be broader effects on the financial situation of companies and sectors in the low-carbon transition. As the value of physical investment in energy production assets that will not be recovered becomes visible to investors, they should reassess publicly listed companies' value, taking into account future earnings. How companies would anticipate, and adapt to, a more stringent climate policy environment is highly uncertain at this stage, and estimates of capital value losses therefore carry more uncertainty than stranded assets. In general, because capital value loss casts a wider net than stranded assets, capital value loss ought to be higher, unless the company has diversified its activities or changed business model, which cannot be evaluated ex ante. Financial stability concerns add to the case for swift action (Carney, 2015).

Stranded assets are not only about energy. A changing climate also weighs on crop yield productivity, which calls for sustainable agriculture investment to taper volatility of future earnings (Morel et al., 2016). The risk of stranding is particularly high in countries like Brazil and Malaysia where deforestation gives way to agriculture (Rautner et al., 2016).

Aligning short-term infrastructure investment plans with long-term, low-emission, climate-resilient development strategies

Barriers to accelerating investment in low-emission and resilient infrastructure include a lack of long-term infrastructure planning that integrates climate mitigation and resilience from the outset, and a lack of a pipeline of bankable and sustainable projects that internalise positive and negative externalities over the lifetime of infrastructure. In order to overcome these barriers, G20 countries should first develop clear infrastructure investment plans that consider mitigation and adaptation as part of their work on developing pathways to 2050.

This section looks at how countries have framed long-term plans, before considering how governments might improve the transparency of infrastructure project pipelines, both to improve the alignment of short-term infrastructure investment with long-term, low-emission, climate-resilient development strategies and to enhance investment flows to that end. The other barriers to accelerate low-emission and resilient infrastructure investment are discussed in Chapter 5.

Develop long-term low-emission strategies to reconcile short-term actions and long-term decarbonisation goals

The Paris Agreement invites parties to communicate by 2020 long-term, low-emission development strategies to 2050 as one of its mechanisms to support strengthening of the international response to climate change. In addition to helping to scale up the ambition of the NDCs, which remain inadequate to reach the Paris Agreement's goals (Chapter 2), such strategies are vital to assist countries in reconciling short-term actions with long-term climate goals. Aligning short-term infrastructure investment plans with long-term, low-emission development strategies will help minimise the risk of both emissions lock-in and stranded assets. Long-term infrastructure investment planning is equally important to ensure flexible, forward-looking investments in resilience, to minimise future impacts from climate change and related economic damage and social hardship.

Post-2030 decarbonisation pathways require different infrastructure, technologies and industrial bases. Countries need to prepare in the next 15 years the technologies and infrastructure necessary to overcome the fossil fuel bias of our economies. In addition, what is considered to be "low-carbon" may differ across countries and over time. Not all "low-carbon" infrastructure is necessarily consistent with the trajectory to a carbon neutral society by the second half of the century; what could be considered as low-carbon in the next five years in some places may not be considered low-carbon elsewhere or on a different timescale.

To date, six countries have submitted mid-century long-term plans to the UNFCCC: Bénin, Canada, France, Germany, Mexico and the United States (Box 3.9). Many other countries are in the process of developing such plans; it is vital that they follow suit. China, India, Russia and the G7 countries have all indicated their intent to develop such strategies before 2020. The 2050 Pathways Platform initiative launched at the UN Climate Change Conference in Marrakech (COP22) represents an important complementary initiative (see Box 2.9).

G20 leaders recognised at the 2014 G20 Summit in Brisbane a lack of a clear pipeline of bankable infrastructure projects as one barrier to infrastructure investment. The lack of information on the pipeline of infrastructure projects makes it difficult to match investment needs and investors, including for low-emission, climate-resilient infrastructure. Providing detailed, comprehensive information on infrastructure projects is key to sending the right signals to private stakeholders to invest in the transition. The lack of information also makes it difficult to carry out a cross-country assessment of consistency of infrastructure plans with long-term mitigation and adaptation goals.

This challenge is particularly important for transitional or "bridge" technologies. Switching from oil or coal to natural gas, for example, will reduce GHG emissions and help countries achieve their 2030 targets and NDCs. But in the mid-term it may generate infrastructure that is costly to replace as further decarbonisation is necessary. There would then be a choice either to let the asset become stranded or to lock in its emissions and accept a continued dependence on fossil fuels that could prevent countries from achieving 2050 targets.

Retrofitting infrastructure post-construction, or stranding assets before the end of their economic life, can be very costly – more costly than designing infrastructure from the outset to take into account climate considerations (Corfee-Morlot et al., 2012; NCE, 2016). To minimise the scale of such problems, each country needs to define now which low-emission options and technologies are consistent with its low-emission pathway to 2050 and beyond, as well as the timing with which new and existing assets need to be deployed and/or phased out. Given the uncertainties associated with the deployment of technologies that are necessary for low-emission pathways (e.g. BECCS), there is a need for a continual reassessment of ambition, as set out in the Paris Agreement.

How do strategic infrastructure plans match up with long-term mitigation and adaptation goals?

At the 2014 G20 Summit in Brisbane, G20 leaders recognised that "tackling global investment and infrastructure shortfalls is crucial to lifting growth, job creation and productivity" and endorsed the Global Infrastructure Initiative (GII), a multi-year work programme to improve the quality of public and private infrastructure investment. In 2015, the G20 Investment and Infrastructure Working Group (IIWG) conducted a voluntary survey to compile information on countries' investment strategies, including the main challenges being addressed, policy priorities, and the policy context of these strategies. This section draws on that work, which remains in progress, in reviewing the extent to which current investment plans and pipelines of infrastructure projects are consistent with climate goals in G20 countries (Table 3.5).

Box 3.9. **Examples of mid-century long-term plans under the Paris Agreement**

France has committed to reducing carbon emissions by 40% by 2030, compared with 1990 levels, and by 75% by 2050. This means that annual emissions reductions must accelerate from 8 megatonnes of carbon dioxide equivalent ($MtCO_2eq$) per year to 9-10 $MtCO_2eq$. Sectoral targets are spelled out for three "carbon budget" periods – 2015-18, 2019-23 and 2024-28 – followed by a long-term target to be achieved by 2050. The national low-carbon strategy is founded on two pillars: including carbon footprint reductions as a key consideration in all economic decisions; and redirecting investments to support the energy transition, through interventions such as environmental quality labels, guaranteeing public funds, and gradually increasing carbon taxes without increasing the overall tax burden.

The United States has committed to reducing its GHG emissions by 26-28% below its 2005 levels by 2025, making every effort to reach a 28% reduction (including LULUCF). It considers this target to be in line with a straight-line emission reduction pathway from 2020 to deep, economy-wide emissions reduction of 80% or more by 2050. To reach these targets, the government has set out three pillars for action:

- shifting to a low-carbon energy system, while putting a particular emphasis on *i)* increasing the energy efficiency of buildings, vehicles and plug-in appliances, *ii)* decarbonising electricity, and *iii)* shifting to clean electricity and low-carbon fuels in transport, buildings and industry;
- carbon sequestration and removal, taking advantage of the country's natural land resources and their capacity to continue to act as a net carbon sink;

Box 3.9. **Examples of mid-century long-term plans under the Paris Agreement** *(cont.)*

- reducing emissions from non-CO_2 gases, notably via the introduction of *i)* stringent standards and incentives to limit CH_4 emissions from oil and gas production and from landfills; and *ii)* new technologies and best practices for livestock agriculture.

Germany's Climate Action Plan 2050 (adopted in November 2016) sets out to obtain extensive GHG neutrality by 2050, which implies reducing total GHG emissions by 80-95% from 1990 levels. The strategy includes a mid-term target of 55% emissions reduction by 2030, and provides several strategic measures, including:

- sector-specific emissions reduction targets for 2030 that will undergo an impact assessment and possibly be revised in 2018;
- a road map towards an almost climate-neutral building stock;
- a commission for growth, structural change and regional development, which will bring together stakeholders from different levels of government, business, industry and various regions, in order to develop strategies for implementation of the Climate Action Plan by the end of 2018.

Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy sets out to cut GHG emissions by 80% by 2050 from 2005 levels. The strategy is not policy prescriptive, but seeks to inform the Pan-Canadian Framework on Clean Growth and Climate Change, and more generally the conversation on how Canada can achieve a low-carbon economy. It describes modelling analyses that illustrate various scenarios towards deep emissions reductions and outlines potential GHG abatement opportunities. Furthermore, it identifies the areas in which emissions reduction will be more challenging, thus requiring an increased policy focus. The Pan-Canadian Framework has four pillars: *i)* pricing carbon pollution; *ii)* complementary measures to further reduce emissions across the economy; *iii)* measures to adapt to the impacts of climate change and build resilience; and *iv)* actions to accelerate innovation, support clean technology, and create jobs.

Sources: FMESDE (n.d.); GFMoENBN (2016); Government of Canada (2016); Government and Provinces of Canada (2016); White House (2016); UNFCCC (2015).

Table 3.5. **Overview of infrastructure plans in the G20 countries**

COUNTRY	Adaptation strategy incl. in infrastructure plan	Mitigation strategy incl. in infrastructure plan	ENERGY						TRANSPORT												WATER						AFOLU					
			Fossil fuels			Renewables			Rail/road			Electric v.			Airports			Ports			WSS			Flood			Agriculure			Forests		
			P	B	T	P	B	T	P	B	T	P	B	T	P	B	T	P	B	T	P	B	T	P	B	T	P	B	T	P	B	T
Argentina			■	■		■	■	■	■	■	■				■		■	■	■								■	■	■			
Australia*	✓	✓	■	■				■	■	■					■	■		■	■		■	■										
Brazil	✓	✓	■	■	■	■	■	■	■	■	■				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			■
Canada*	✓	✓					■			■				■		■			■			■			■							
China	✓	✓						■																					■			■
France		✓			■			■						■																		
Germany*		✓						■	■	■	■			■				■	■	■				■	■							
India*	✓	✓			■			■		■				■		■			■									■				
Indonesia*	✓	✓	■	■	■			■	■	■					■	■		■	■	■	■	■										
Italy		✓						■			■									■												
Japan	✓	✓						■			■			■												■						
Korea		✓						■						■																		
Mexico			■	■	■	■	■	■	■	■	■				■	■	■	■	■	■	■	■	■	■	■	■						
Russia		✓		■	■			■																								
Saudi Arabia					■			■		■	■																					
South Africa	✓	✓	■		■			■	■		■				■			■					■			■	■					
Turkey					■			■			■						■			■					■				■		■	
UK	✓	✓	■	■	■	■	■	■	■	■	■				■	■		■	■		■	■	■	■	■	■						■
US**																																

Notes: a. The table does not provide an overview of the countries' emissions reduction targets, as stated in the NDCs. These are reflected in Annex 2.A1. This table provides a snapshot of the coverage of national infrastructure plans in G20 countries, and the extent to which adaptation and mitigation are mainstreamed into those plans. b. Abbreviations: WSS: Water supply and sanitation ; AFOLU: Agriculture, forestry and other land use; c. Shaded cells indicate the availability of an infrastructure plan (P), associated budget (B), and target (T); d. Infrastructure plans (P) must include details on the location, type (new construction vs renewal), and the action(s) to be performed in each project (e.g. capacity strengthening, efficiency measures or safety enhancing measures) to be captured in the table; e. Outcome-based targets (T) included are those expressed as, inter alia, kilometres (road and rail), megawatts (energy), number of units (EVs), a percentage (the share of renewable energy in total energy supply or the share of roads that will be upgraded), or hectares (afforestation). Sectoral emissions reduction targets are not taken into account in the table, as these alone provide no information about the kind of infrastructure measures that will be implemented. * These are federal states, where infrastructure projects to a large extent are planned at a state level. The table reflects national plans only; ** The US has stated that it will issue an infrastructure plan during 2017; however, this was not available at the time the information for this table was compiled.

Mainstreaming climate mitigation and adaptation in infrastructure plans

Low-emission growth and economic development are often presented, erroneously, as competing priorities. While there will always be trade-offs and competing objectives between different goals for infrastructure investment, many climate-friendly infrastructure options also provide relief from problems like congestion, air pollution and access to energy in rural locations that have to date lacked easy answers (Box 3.10). This can be a boost to mainstreaming of climate considerations into infrastructure plans. As with any large-scale investments, the essential task is to ensure that all the costs and benefits are considered coherently at the outset, taking into account the time frames during which the infrastructure will be operated.

Table 3.5 shows that only 9 countries – less than half of the G20 – have integrated both mitigation and adaptation considerations into infrastructure planning. An additional four countries only mention mitigation. Five mention neither climate mitigation nor adaptation. In addition, only seven G20 countries have made available a detailed plan of infrastructure projects covering at least three of the four economic sectors of primary concern from a climate perspective (e.g. transport, energy, water and AFOLU, addressed below). The majority cover only one of these areas, or have not communicated infrastructure plans in these areas at all. There is therefore considerable scope for G20 countries to heighten their efforts to both align infrastructure plans across key economic sectors with climate mitigation and adaptation goals, and communicate those plans.

For transport, five G20 countries have provided detailed plans for road, rail, ports and airport infrastructure. Five more have an overall target specific to road and rail. Many countries that do not have a detailed plan tend to either have specific targets (e.g. Turkey) and/or allocated a budget for infrastructure (e.g. India). While these are promising signs, there is a need to better shape and define the future nature of transport in these countries for the transition. China, Russia and the United States are yet to communicate targets, budgets and plans for transport infrastructure. Infrastructure to facilitate the deployment of electric vehicles – such as public charging stations – is also important to the transition in the transport sector. However, to date, G20 infrastructure plans make no mention of concrete charging station infrastructure.

For energy, 17 G20 countries have defined renewable energy targets. Most, however, have not communicated a pipeline of projects for the years to come. Further, Table 3.5 also indicates that fossil-fuel related energy is still prevalent in many governmental plans. Ten G20 countries have targets for fossil fuel energy.

Water and AFOLU receive little attention in national infrastructure plans. For water supply and sanitation, only five countries have defined infrastructure plans. One additional country has set aside an envelope of funding for this issue. As for AFOLU, three countries have defined a pipeline of projects in agriculture. A further three have either established a budget or a target but are yet to provide information on the specific projects involved. In terms of forestry, information is even more scarce: targets exist in only three G20 countries, and one country has identified a budget to invest in this sector. Given the importance of these two sectors in transiting to low-emission, climate-resilient economies, there is scope for G20 countries to develop more robust plans, budgets and targets in their strategies in these areas.

Box 3.10. **Examples of co-benefits between low-carbon infrastructure and other SDGs**

Air pollution

Improved air quality is one of several co-benefits of climate action that have positive implications for human health. The OECD estimates that in 2010, 3 million people died prematurely because of outdoor air pollution. Unless policies become more stringent, projections suggest 6-9 million people will die prematurely each year by 2060. These deaths are largely projected to take place in densely populated regions with high concentrations of PM2.5 (particulate matter 2.5 micrometers or less in diameter) and, to a lesser extent, ozone (especially China and India) and in regions with aging populations, such as China and Eastern Europe.

In addition, increasing concentrations of PM2.5 and ozone are projected to lead to substantially more cases of illness. This will imply more hospital admissions, greater health expenditure, a higher number of lost working days and limitations on normal daily activities. Air pollution-related healthcare costs are projected to increase from USD 21 billion in 2015 (using constant 2010 USD and PPP exchange rates) to USD 176 billion in 2060, reflecting both a large number of additional cases of illness due to air pollution, and a projected increase in healthcare costs per illness. While a reduction in the burning of fossil fuels is likely to decrease the risk of heart and lung diseases, such as lung cancer, as well as neurologic disorders, other measures also provide clear benefits for human health. For example, replacing cars by more active forms of transport such as walking and cycling can reduce obesity, lung disease, heart disease, breast cancer and depression (Armstrong, 2012).

If climate change mitigation and air pollution policies are integrated, air quality could improve to a point where 40% of the global population currently exposed to dangerous PM levels would breathe air that meets World Health Organisation clean air quality guidelines. At the same time, expenditure on air pollution control will be reduced by EUR 250 billion in 2050. According to the estimates provided by the study, one-third of the total financial co-benefits by 2050 will occur in China, while annual cost savings of EUR 35 billion are estimated for the European Union, provided the current air pollution legislation and climate policies are adopted in parallel (Rafaj et al., 2012).

Reducing congestion

A number of governments have implemented Bus Rapid Transit (BRT) systems to reduce local air pollution and improve health. National railway systems have also reduced congestion, while improving access to remote, small or low-income communities, and supporting economic development and trade (Ang and Marchal, 2013). By improving connectivity and reducing congestion, these policies can boost the contribution of urban centres to productivity growth (OECD, 2015b).

Sources: OECD (2015b; 2016a); Armstrong (2012); Rao et al. (2016); Rafaj et al. (2012).

Improving the transparency of infrastructure project pipelines

Infrastructure development plans and project pipeline information that are inaccessible, incomplete or poorly aligned with long-term climate mitigation and adaptation goals are likely to hinder the flow of infrastructure investment in support of climate goals. Several mechanisms are available to help governments improve the transparency of infrastructure project pipelines.

The Global Infrastructure Hub (GI Hub) launched by the G20 in 2014 could prove a useful tool to increase transparency and strengthen the global pipeline of private and public infrastructure investment opportunities. It showcases investment-ready projects to multilateral banks and private investors. As of February 2017, the project pipeline consisted of 44 projects from eight countries, with a total value of more than USD 29 million (although several early-stage projects have not yet disclosed their values) (GI Hub, n.d.). Out of the eight countries that have contributed to the GI Hub Project Pipeline, only four are G20 countries. The participation of more G20 countries in the Hub would provide a more complete and transparent picture to investors of the direction of infrastructure plans as a whole.

Other global initiatives also help to improve the transparency of infrastructure project pipelines. These can be divided into influencers, mobilisers and tool providers (Mercer and IDB, 2016). *Influencers* – such as the OECD Centre on Green Finance and Investment, the New Climate Economy and the Global Infrastructure Investor Association – provide research and leadership to align infrastructure investment plans with sustainability targets. *Mobilisers*, such as the GI Hub, assist *i)* governments in developing bankable projects and *ii)* investors in funnelling funds into those projects. *Tool providers* – such as the IRENA Navigator and the World Bank's REFINe – aim at facilitating the integration of environmental and social components of infrastructure projects into investment decisions (Mercer and IDB, 2016).

Other platforms provide information on public-private partnerships (PPPs) for infrastructure projects, with the aim of matching investors to projects. For example, the World Bank's Private Participation in Infrastructure (PPI) Project Database contains data on 6 400 infrastructure projects in 139 low- and middle-income countries (World Bank, n.d.b). The World Bank also provides a range of other resources on PPPs for infrastructure, including regional and sectorial updates on overall infrastructure investments through PPPs, as well as sample agreements, checklists, risk matrices, standard bidding documents and other material facilitating the establishment of PPPs, notably in developing countries (World Bank, n.d.c; n.d.d). Strengthening those existing tools to improve the data quality on existing infrastructure investments and future plans and needs is a key priority for G20 countries, and critical to gain the confidence of private sector investors in low-carbon, climate-resilient infrastructure (Chapter 5).

Notes

1. All estimates were converted to 2015 USD for comparability.
2. Bhattacharya et al. (2016b) explain that such an increase is the result of a different methodological approach, and argue that previous estimate failed to reflect the increase in infrastructure spending over the past decade, mainly in middle-income countries. Batthacharya et al.'s (2016b) methodological approach consists of calculating an updated baseline of infrastructure spending in 2015 for major countries, and projecting investment requirements on assumptions of growth and investment rates (which are in turn based on assessments of investment plans and identified gaps across major economies and regions).
3. Details of the assumptions on costs are available in IEA (2017).
4. Pre-construction includes power plants announced, in pre-permit development and permitted. "On hold" includes plants announced as being on hold. In the absence of an announcement that the sponsor is putting its plans on hold, a project is considered "shelved" if there are no reports of activity over a period of two years. At the global level, coal power plants in pre-construction development and "on hold" amount to 570 GW and 607 GW respectively.
5. See Iyer et al. (2015); Rozenberg, Vogt-Schilb and Hallegatte (2014); Johnson et al. (2015); Fay et al. (2015).
6. Although there is value in assessing the cost of shifting the building stock to meet the energy requirements of a low-carbon transition, retrofitting and renovation would add value to buildings, which is not the case of stranded assets in the energy sector. IRENA estimates stranded assets in the buildings sector to amount to USD 12.5 trillion in its Delayed Policy Action case and USD 5 trillion in the REmap reference case; computed as "the difference between cost of deep retrofit and the additional cost to build a new fossil-free building" (IRENA, 2017a).
7. It also assumes oil demand would be at 45% (IRENA) and 41% (IEA) of today's level by 2050. Other methodological differences include that IRENA estimates the impact on the oil and gas sector through the capital value of registered companies, then extrapolates to global oil and gas production. For power and industry, it calculates stranded assets based on the nominal value of a plant shutting down before the end of its economic lifetime.

References

Agrawala, S. and S. Fankhauser (2008), *Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments, OECD Publishing, Paris,* http://doi.org/10.1787/9789264046214-en.

Alexandratos, N. and J. Bruinsma (2012), "World Agriculture Towards 2030/2050", Food and Agriculture Organization of the United Nations, Rome, www.fao.org/docrep/016/ap106e/ap106e.pdf.

Ang, G. and V. Marchal (2013), "Mobilising Private Investment in Sustainable Transport: The Case of Land-Based Passenger Transport Infrastructure", OECD Publishing, Paris, http://doi.org/10.1787/5k46hjm8jpmv-en.

Ansar, A. et al. (2016), "Does infrastructure investment lead to economic growth or economic fragility? Evidence from China", *Oxford Review of Economic Policy*, Vol. 32/3, Oxford University Press, Oxford, pp. 360-390, https://doi.org/10.1093/oxrep/grw022.

Armstrong, F. (2012), *Our Uncashed Dividend: The Health Benefits of Climate Action*, Climate and Health Alliance and the Climate Institute, Sydney, www.climateinstitute.org.au/verve/_resources/OurUncashedDividend_CAHAandTCI_August2012.pdf.

AsDB (2017), *Meeting Asia's Infrastructure Needs,* Asian Development Bank, Manila, http://dx.doi.org/10.22617/FLS168388-2.

ATAG (2014), *Aviaton: Benefits beyond borders, Air Transport Action Group*, Geneva, http://aviationbenefits.org/.

Berg, A. et al. (2012), *Public Investment, Growth, and Debt Sustainability: Putting Together the Pieces, International Monetary Fund, Washington DC,* www.imf.org/external/pubs/cat/longres.aspx?sk=25962.0.

Bhattacharya A., et al. (2016a), *Framework for Assessing the Role of Sustainable Infrastructure*, Brookings Institution, Washington DC.

Bhattacharya, A., et al. (2016b), *Delivering on Sustainable Infrastructure for Better Development and Better Climate, Brookings Institution, Washington DC,* www.brookings.edu/research/delivering-on-sustainable-infrastructure-for-better-development-and-better-climate/.

Booz Allen Hamilton (2007), *The global infrastructure investment deficit, Booz Allen Hamilton, McLean, Virginia*.

Brandon, N.P. et al. (2016), *UK Research Needs in Grid Scale Energy Storage Technologies*, Energy Superstore, Oxford and London, https://ora.ox.ac.uk/objects/uuid:c0a1d73e-3783-4298-b16b-d6108c241151.

Budischak, C. et al. (2013), "Cost-minimized combinations of wind power, solar power and electrochemical storage, powering the grid up to 99.9% of the time", *Journal of Power Sources*, Vol. 225, Elsevier, Amsterdam, pp. 60-74, http://dx.doi.org/10.1016/j.jpowsour.2012.09.054.

Caldecott, B. et al. (2017), "Stranded Assets and the Environment", *Journal of Sustainable Finance and Investment, Vol. 7/1, Taylor and Francis, Abingdon, United Kingdom, pp. 1-138*. www.tandfonline.com/toc/tsfi20/7/1?nav=tocList.

Calderon, C. and L. Serven (2014), "Infrastructure, Growth and Inequality: An Overview", World Bank, Washington DC, http://hdl.handle.net/10986/20365.

Carbon Tracker Initiative (2013), *Unburnable Carbon 2013: Wasted Capital and Stranded Assets, Carbon Tracker Initiative, London,* http://carbontracker.live.kiln.digital/Unburnable-Carbon-2-Web-Version.pdf.

Carney, M. (2015), *Breaking the tragedy of the horizon – climate change and financial stability, speech, Bank of England, London,* www.bankofengland.co.uk/publications/Pages/speeches/2015/844.aspx.

Carrington, D. (2016), "EasyJet's plans for a hybrid fleet, using hydrogen fuel cells", CNN, www.cnn.com/2016/02/02/aviation/easyjet-hybrid-plane-hydrogen-fuel-cell/index.html.

Climate Policy Initiative (2013), *Buildings Energy Efficiency in China, Germany and the United States*, Climate Policy Initiative, San Francisco, https://climatepolicyinitiative.org/wp-content/uploads/2013/04/Buildings-Energy-Efficiency-in-China-Germany-and-the-United-States.pdf.

Corfee-Morlot, J. et al. (2012), "Towards a Green Investment Policy Framework: The Case of Low-Carbon, Climate-Resilient Infrastructure", OECD Publishing, Paris, http://dx.doi.org/10.1787/5k8zth7s6s6d-en.

Darling, R.M. et al. (2014), "Pathways to low-cost electrochemical energy storage: a comparison of aqueous and nonaqueous flow batteries", *Energy and Environmental Science, Vol. 7, Royal Society of Chemistry, London, pp. 3459–3477,* http://dx.doi.org/10.1039/C4EE02158D.

Delgado, C., et al. (2015), *Restoring and protecting agricultural and forest landscapes and increasing agricultural productivity, New Climate Economy,* http://newclimateeconomy.report/2015/wp-content/uploads/sites/3/2015/12/NCE-restoring-protecting-ag-forest-landscapes-increase-ag.pdf.

Development Bank of Southern Africa (2012), *The State of South Africa's Economic Infrastructure: Opportunities and Challenges 2012*, Development Planning Division, Development Bank of Southern Africa, Johannesburg, www.gov.za/sites/www.gov.za/files/State%20of%20SAs%20Economic%20Infrastructure%20Report%202012a.pdf.

DfT (2007), *Low Carbon Transport Innovation Strategy*, UK Department for Transport, London, http://webarchive.nationalarchives.gov.uk/20081022212629/http:/www.dft.gov.uk/pgr/scienceresearch/technology/lctis/lctisdocpdf.

Dietz, S. et al. (2016), "Climate value at risk of global financial assets", *Nature Climate Change, Vol. 6, Springer Nature, London, pp. 676-679,* http://dx.doi.org/10.1038/nclimate2972.

Elgowainy, A. et al. (2012), "Life Cycle Analysis of Alternative Aviation Fuels in GREET", Argonne National Laboratory, Lemont, Illinois, https://greet.es.anl.gov/publication-aviation-lca.

Epstein, A.H. (2014), "Aeropropulsion for Commercial Aviation in the Twenty-First Century and Research Directions Needed", *AIAA Journal*, Vol. 52, American Institute of Aeronautics and Astronautics, Reston, Virginia, pp. 901–911, http://dx.doi.org/10.2514/1.J052713.

Erickson, E.M. et al. (2015), "Review—Development of Advanced Rechargeable Batteries: A Continuous Challenge in the Choice of Suitable Electrolyte Solutions", *Journal of the Electrochemical Society*, Vol. 162/14, Electrochemical Society, Pennington, New Jersey, pp. A2424–A2438, http://dx.doi.org/10.1149/2.0051514jes.

FAO (n.d.), *FAOSTAT*, Statistics Division, Food and Agriculture Organization of the United Nations, Rome Italy (accessed December 2016), www.fao.org/faostat/en/.

Fay, M., et al. (2015), *Decarbonizing Development: Three Steps to a Zero-Carbon Future, World Bank, Washington DC,* http://hdl.handle.net/10986/21842.

Fennell, P.S. et al. (2012), "CCS from industrial sources", *Sustainable Technologies, Systems and Policies*, Vol. 17, Hamad bin Khalifa University Press, Doha, http://dx.doi.org/10.5339/stsp.2012.ccs.17.

Florin, N. and P.S. Fennell (2010), *Carbon capture technology: future fossil fuel use and mitigating climate change, Grantham Institute, Imperial College, London,* www.imperial.ac.uk/grantham/publications/briefing-papers/carbon-capture-technology-future-fossil-fuel-use-and-mitigating-climate-change---grantham-briefing-paper-3.php.

FMESDE (n.d.), "Strategie National Bas-carbone", French Ministry of Ecology, Sustainable Development and Energy, Paris, http://unfccc.int/files/mfc2013/application/pdf/fr_snbc_strategy.pdf.

Fotouhi, A. et al. (2016), "A review on electric vehicle battery modelling: From Lithium-ion toward Lithium–Sulphur", *Renewable and Sustainable Energy Reviews*, Vol. 56, Elsevier, Amsterdam, pp. 1008–1021, http://dx.doi.org/10.1016/j.rser.2015.12.009.

GFMoENBN (2016), *Climate Action Plan 2050,* German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, Berlin, www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_kurzf_en_bf.pdf.

GI Hub (n.d.), "The Pipeline", Global Investment Hub, https://pipeline.gihub.org/, (accessed on 15 February 2017).

Government and Provinces of Canada (2016), *Pan-Canadian Framework on Clean Growth and ClimateChange*, Government of Canada, www.canada.ca/content/dam/themes/environment/documents/weather1/20161209-1-en.pdf.

Global Coal Plant Tracker (2017), *Global coal plant tracker,* http://endcoal.org/tracker/, (accessed on 28 February 2017).

Government of Canada (2016), *Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy*, Government of Canada Publications, http://publications.gc.ca/pub?id=9.825953&sl=0.

Grande, L. et al. (2015), "The Lithium/Air Battery: Still an Emerging System or a Practical Reality?", *Advanced Materials*, Vol. 27/5, Wiley, Hoboken, pp. 784–800, http://dx.doi.org/10.1002/adma.201403064.

Granoff, I. et al. (2015), "Zero Poverty, Zero Emissions: Eradicating Extreme Poverty in the Climate Crisis", Overseas Development Institute, London, www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9844.pdf.

Gurwick, N.P. et al. (2013), "A Systematic Review of Biochar Research, with a Focus on Its Stability in situ and Its Promise as a Climate Mitigation Strategy", *PLOS ONE, Vol. 8/9, PLOS, San Francisco,* http://dx.doi.org/10.1371/journal.pone.0075932.

Gutman, J., A. Sy and S. Chattopadhyay (2015), *Financing African infrastructure: Can the world deliver?* Brookings Institution, Washington DC, www.brookings.edu/research/financing-african-infrastructure-can-the-world-deliver/.

Hisatomi, T. et al. (2014), "Recent advances in semiconductors for photocatalytic and photoelectrochemical water splitting", *Chemical Society Reviews*, Vol. 43, Royal Society of Chemistry, London, pp. 7520–7535, http://dx.doi.org/10.1039/C3CS60378D.

Hughes, G., P. Chinowsky and K. Strzepek (2010), *The Costs of Adapting to Climate Change for Infrastructure*, World Bank, Washington DC, http://siteresources.worldbank.org/EXTCC/Resources/407863-1229101582229/DCCDP_2Infrastructure.pdf.

Ignaciuk, A. (2015), "Adapting Agriculture to Climate Change: A Role for Public Policies", OECD Publishing, Paris, http://dx.doi.org/10.1787/5js08hwvfnr4-en.

Ignaciuk, A. and D. Mason-D'Croz (2014), "Modelling Adaptation to Climate Change in Agriculture", OECD Publishing, Paris, http://dx.doi.org/10.1787/5jxrclljnbxq-en.

IPCC (2014), *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York*. http://www.ipcc.ch/report/ar5/wg3/.

IAEA (2016), *Power Reactor Information System, International Atomic Energy Agency, Vienna*, https://www.iaea.org/pris/ (accessed on 30 November 2016).

IEA (2017), *Chapters 1 and 2 in Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System, International Energy Agency/OECD Publishing, Paris*, www.energiewende2017.com/wp-content/uploads/2017/03/Perspectives-for-the-Energy-Transition_WEB.pdf.

IEA (2016a), *World Energy Outlook 2016, IEA/OECD Publishing, Paris*, www.worldenergyoutlook.org/publications/weo-2016/.

IEA (2016b), *World Energy Investment 2016*, IEA/OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264262836-en.

IEA (2016c), *IEA Medium-Term Renewable Energy Market Report 2016: Market Analysis and Forecasts to 2021, IEA/*OECD Publishing, Paris, http://dx.doi.org/10.1787/renewmar-2016-en.

IEA (2016d), *Energy Technology Perspectives 2016*, IEA/OECD Publishing, Paris, http://dx.doi.org/10.1787/energy_tech-2016-en.

IEA (2012), *Energy Technology Perspectives 2012: Pathways to a Clean Energy System*, IEA/OECD Publishing, Paris, http://dx.doi.org/10.1787/energy_tech-2012-en.

IEA (2010), *Energy Technology Perspectives 2010: Scenarios and Strategies to 2050*, IEA/OECD Publishing, Paris, http://dx.doi.org/10.1787/energy_tech-2010-en.

ILO and IILS (2011), "A Review of Global Fiscal Stimulus", International Labour Organisation and International Institute for Labour Studies, Geneva, www.ilo.org/inst/research/addressing-crisis-challenges/discussion-paper-series/WCMS_194175/lang--en/index.htm.

IMF (2014), "Is It Time for an Infrastructure Push? The Macroeconomic Effects of Public Investment", in *World Economic Outlook 2014: Legacies, Clouds, Uncertainties*, International Monetary Fund, Washington DC, www.imf.org/external/pubs/ft/weo/2014/02/.

IRENA (2017a), *Chapter 3 in Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System, International Renewable Energy Agency, Abu Dhabi*, www.energiewende2017.com/wp-content/uploads/2017/03/Perspectives-for-the-Energy-Transition_WEB.pdf.

IRENA (2017b), "Rethinking Energy: Accelerating the global energy transformation", International Renewable Energy Agency, Abu Dhabi. www.irena.org/DocumentDownloads/Publications/IRENA_REthinking_Energy_2017.pdf.

Iyer, G. et al. (2015), "The Contribution of Paris to Limit Global Warming to 2°C", *Environmental Research Letters, Vol. 10/12, IOP Publishing, Bristol*, http://dx.doi.org/10.1088/1748-9326/10/12/125002.

Johnson, N. et al. (2015), "Stranded on a low-carbon planet: Implications of climate policy for the phase-out of coal-based power plants", *Technological Forecasting and Social Change, Vol. 90/A, Elsevier, Amsterdam*, http://dx.doi.org/10.1016/j.techfore.2014.02.028.

Kennedy, C. and J. Corfee-Morlot (2012), "Mobilising Investment in Low Carbon, Climate Resilient Infrastructure", OECD Environment Working Papers, No. 46, OECD Publishing, http://dx.doi.org/10.1787/5k8zm3gxxmnq-en.

LCICG (2014), *Coordinating Low Carbon Technology Innovation Support: The LCICG's Strategic Framework*, Low Carbon Innovation Co-ordination Group, London, www.lowcarboninnovation.co.uk/working_together/strategic_framework/overview/.

Magnuson, A. et al. (2009), "Biomimetic and Microbial Approaches to Solar Fuel Generation, *Accounts of Chemical Research*, Vol. 42/12, American Chemical Society, Washington DC, pp. 1899–1909, http://dx.doi.org/10.1021/ar900127h.

Mercer and IDB (2016), *Building a bridge to sustainable infrastructure: Mapping the global initiatives that are paving the way*, Mercer and Inter-American Development Bank, Washington, www.mercer.com/our-thinking/building-a-bridge-to-sustainable-infrastructure.html.

Moniz, S.J.A. et al. (2015), "Visible-light driven heterojunction photocatalysts for water splitting – a critical review", *Energy and Environmental Science, Vol. 8, Royal Society of Chemistry, London, pp. 731–759,* http://dx.doi.org/10.1039/C4EE03271C.

Morel, A. et al. (2016), *Stranded Assets in Palm Oil Production: A Case Study of Indonesia*, Smith School of Enterprise and the Environment, University of Oxford, Oxford, www.smithschool.ox.ac.uk/research-programmes/stranded-assets/Stranded_Assets_in_Palm_Oil_Production.pdf.

Napp, T. (forthcoming), *A survey of key technological innovations for the low-carbon economy, Grantham Institute, Imperial College, London.*

National Economic Council and the President's Council of Economic Advisers (2014), *An Economic Analysis of Transportation Infrastructure Investment*, White House, Washington DC, https://obamawhitehouse.archives.gov/sites/default/files/docs/economic_analysis_of_transportation_investments.pdf.

NCE (2016), *The Sustainable Infrastructure Imperative: Financing for Better Growth and Development, New Climate Economy, Washington DC and London,* http://newclimateeconomy.report/2016/wp-content/uploads/sites/4/2014/08/NCE_2016Report.pdf.

NCE (2014), *Better Growth, Better Climate*, New Climate Economy, Washington DC and London, http://newclimateeconomy.report/2014/.

Nykvist, B. and M. Nilsson (2015), "Rapidly falling costs of battery packs for electric vehicles", *Nature Climate Change*, Vol. 5, Springer Nature, London, pp. 329–332. http://dx.doi.org/10.1038/nclimate2564.

OECD (2016a), *The Economic Consequences of Outdoor Air Pollution*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264257474-en.

OECD (2016b), "Producer and Consumer Support Estimates", database, www.oecd.org/tad/agricultural-policies/producerandconsumersupportestimatesdatabase.htm (accessed on 10 April 2017).

OECD (2015a), *Aligning Policies for a Low-carbon Economy*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264233294-en.

OECD (2015b), *Governing the City*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264226500-en.

OECD (2014), *Green Growth Indicators for Agriculture: A Preliminary Assessment*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264223202-en.

OECD (2012), *Strategic Transport Infrastructure Needs to 2030*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264114425-en.

OECD (2006), *Infrastructure to 2030: Telecom, Land Transport, Water and Electricity*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264023994-en.

OECD/ITF (2017), *ITF Transport Outlook 2017*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789282108000-en.

Pan, Y. (2016), "China's Urban Infrastructure Challenges", *Engineering*, Vol. 2/1, Elsevier, Amsterdam, pp. 29-32, http://doi.org/10.1016/J.ENG.2016.01.007.

Pardee Center (2014), "Patterns of potential human progress", Pardee Center, University of Denver, Denver, http://pardee.du.edu/pphp-4-building-global-infrastructure.

Pardee Center (n.d.), "Access Ifs", *International Futures Model,* Pardee Center, University of Denver, Denver, http://pardee.du.edu/access-ifs.

Parry, M. et al. (2009), *Assessing the costs of adaptation to climate change: A review of the UNFCCC and other recent estimates,* International Institute for Environment and Development and Grantham Institute, Imperial College, London, http://pubs.iied.org/pdfs/11501IIED.pdf.

Platts WEPP (2017), *World Electric Power Plants Database*, Platts, London, www.platts.com/products/world-electric-power-plants-database (accessed on 31 March 2017).

Pultarova, T. (2016), "Hydrogen-powered aircraft takes to sky in Germany", *Engineering and Technology,* Institute of Engineering and Technology, Stevenage, United Kingdom, https://eandt.theiet.org/content/articles/2016/09/hydrogen-powered-aircraft-takes-to-sky-in-germany/.

Rafaj, P. et al. (2012), "Co-benefits of post-2012 global climate mitigation policies", International Institute for Applied Systems Analysis, Laxenburg, Austria, http://pure.iiasa.ac.at/10378/.

Rao, S. et al. (2016), "A multi-model assessment of the co-benefits of climate mitigation for global air quality", *Environmental Research Letters, vol. 11/124013, IOP Publishing, Bristol,* http://iopscience.iop.org/article/10.1088/1748-9326/11/12/124013/pdf.

Rautner, M., et al. (2016), *Managing the Risk of Stranded Assets in Agriculture and Forestry,* Chatham House, London, www.chathamhouse.org/publication/managing-risk-stranded-assets-forestry-and-agriculture.

Rozenberg, J., Vogt-Schilb, A. and Hallegatte, S. (2014), *Transition to clean capital, irreversible investment and stranded assets, World Bank, Washington DC,* http://documents.worldbank.org/curated/en/768841468171252748/Transition-to-clean-capital-irreversible-investment-and-stranded-assets.

Shearer, C. et al. (2017), *Boom and Bust 2017: Tracking the global coal plant pipeline, Global Coal Plant Tracker,* http://endcoal.org/wp-content/uploads/2017/03/BoomBust2017-English-Final.pdf.

Stotsky, J. and M. Ghazanchyan (2013), *Drivers of Growth: Evidence from Sub-Saharan Africa, International Monetary Fund, Washington DC,* www.imf.org/en/Publications/WP/Issues/2016/12/31/Drivers-of-Growth-Evidence-from-Sub-Saharan-African-Countries-41064.

UKCCSRC (2015), *RAPID Research and Pathways to Impact Development: Handbook 1.1b – Research Area Summaries and Needs*, United Kingdom Carbon Capture and Storage Research Centre, Sheffield and Edinburgh, https://ukccsrc.ac.uk/sites/default/files/documents/content_page/RAPID%201_1b.pdf.

UN (n.d.), *UN Comtrade Database, United Nations,* https://comtrade.un.org/ (accessed 30 April 2017).

UN (2016), *The Sustainable Development Goals Report 2016, United Nations,* https://unstats.un.org/sdgs/report/2016/The%20Sustainable%20Development%20Goals%20Report%202016.pdf.

UNCTAD (2016), *Review of Maritime Transport 2016: The long-term growth prospects for seaborne trade and maritime businesses, United Nations Conference on Trade and Development, Geneva,* http://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=1650.

UNFCCC (2015), "Intended Nationally Determined Contribution of Mexico", UNFCCC, Bonn, www4.unfccc.int/submissions/INDC/Published%20Documents/Mexico/1/MEXICO%20INDC%2003.30.2015.pdf.

UNFCCC (2007), *Background Paper on Analysis of Existing and Planned Investment and Financial Flows Relevant to the Development of Effective and Appropriate International Response to Climate Change*, UNFCCC, Bonn, http://unfccc.int/files/cooperation_and_support/financial_mechanism/application/pdf/background_paper.pdf.

Vogt-Schilb, A. & S. Hallegatte (2014), *Marginal abatement cost curves and the optimal timing of mitigation measures.* Energy Policy 66, 645–653. 2.

White House (2016), "United States Mid-Century Strategy for Deep Decarbonisation", White House, Washington DC, http://obamawhitehouse.archives.gov/sites/default/files/docs/mid_century_strategy_report-final.pdf.

Woetzel, J. et al. (2016), *Bridging Global Infrastructure Gaps, McKinsey Global Institute,* www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/bridging-global-infrastructure-gaps.

Workman, M. et al. (2011), "An assessment of options for CO_2 removal from the atmosphere", *Energy Procedia*, Vol. 4, Elsevier, Amsterdam, pp. 2877–2884, http://dx.doi.org/10.1016/j.egypro.2011.02.194.

World Bank (2010, *The Costs of Adapting to Climate Change for Infrastructure,* World Bank, Washington DC, http://siteresources.worldbank.org/EXTCC/Resources/407863-1229101582229/DCCDP_2Infrastructure.pdf.

World Bank (n.d.a), *World Development Indicators,* World Bank, Washington DC, http://data.worldbank.org/data-catalog/world-development-indicators (accessed on 15 January 2017).

World Bank (n.d.b), "PPPIRC", World Bank, Washington DC, https://ppp.worldbank.org/public-private-partnership/ (accessed on 15 February 2017).

World Bank (n.d.c), "PPI Resources", World Bank, Washington DC, http://ppi.worldbank.org/resources/ppi-resources (accessed on 15 February 2017).

World Bank (n.d.d), "Public-Private-Partnership in Infrastructure Resource Center", World Bank, Washington DC, https://ppp.worldbank.org/public-private-partnership/ (accessed on 15 February 2017).

WEF (2015), *The Global Competitiveness Report 2015-2016*, World Economic Forum, Geneva, www3.weforum.org/docs/gcr/2015-2016/Global_Competitiveness_Report_2015-2016.pdf.

Zhang, S.S. (2013), "Liquid electrolyte lithium/sulfur battery: Fundamental chemistry, problems, and solutions", *Journal of Power Sources, Vol. 231, Elsevier, Amsterdam, pp. 153–162,* http://dx.doi.org/10.1016/j.jpowsour.2012.12.102.

Annex 534

"Debt-for-Nature Swaps", Michael Occhiolini, *International Economics Department, World Bank,* March 1990

Policy, Research, and External Affairs

WORKING PAPERS

Debt and International Finance

International Economics Department
The World Bank
March 1990
WPS 393

Debt-for-Nature Swaps

Michael Occhiolini

If the spending priorities of the debtor country and donor are the same, these swaps can help debtor countries. But sometimes they do not make fiscal sense. And the future of these swaps may be limited by the Brady Plan's current emphasis on debt reduction.

Policy, Research, and External Affairs

WORKING PAPERS

Debt and International Finance

This paper — a product of the Debt and International Finance Division, International Economics Department — is part of a larger effort in PRE to analyze alternative forms of debt and debt service reduction operations available to developing countries and to assess the potential costs and benefits of these operations. Other analysis along these lines includes studies of debt-equity swaps and of market-based voluntary debt reduction exercises. Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington DC 20433. Please contact Sheilah King-Watson, room S8-025, extension 31047 (34 pages).

Of the three participants in debt-for-nature swaps, international environmental groups benefit the most. These swaps leverage the original donation amount by the difference between the secondary market value and the redemption value of the debt.

As the difference between the redemption and secondary market value declines over time, the environmental group benefits less.

Without further changes in the tax and regulatory environment, there is little reason — except good publicity — for commercial banks to donate their debt to environmental groups. They can realize more by selling their debt on the secondary market.

The debtor country subsidizes the swap by the difference between the redemption value and secondary market of the debt. There is controversy about whether the debtor country benefits from buying back its debt at the secondary market price — let alone at the higher redemption rate usually offered in debt-for-nature swaps.

From a fiscal standpoint, the debt-for-nature swap, unlike a straight donation, can worsen the budget situation if spending on the domestic environmental bond exceeds the debt-service payments on the external debt that is exchanged in the swap.

When resources are limited, spending on debt-for-nature swaps reduces the resources available to other (even higher priority) projects.

The future of these and similar swaps may be limited by the Brady Plan's current emphasis on debt reduction. A debtor country would clearly prefer to have its debt partially forgiven than to swap it for a domestic liability created through a debt-for-nature swap.

Produced at the PRE Dissemination Center

Debt-for-Nature Swaps

by
Michael Occhiolini

Table of Contents

Introduction

Debt-for-nature swaps involve the exchange of a debtor country's external obligation for that country's agreement to use local currency instruments (usually either cash or "environmental bonds") to support a specific environmental project, such as the designation and management of protected areas, the development of conservation management plans, training of park personnel, and environmental education activities.

Although the total amount of debt-for-nature swaps has been limited--$79 million in face value versus $1.3 billion of external debt--the agreements have generated a lot of publicity because of the linkage of external debt reduction with environmental protection in developing countries. While debt-for-nature agreements will never substantially reduce developing-country external debt, they can dramatically increase the amount of funds spent by the debtor country on environmental protection.

Debt-for-nature agreements are often described as deals where everyone benefits: the debtor country reduces its external debt, the environmental group can "leverage" its original donation amount, and banks profit either from selling their debt on the secondary market or from the publicity value of donating the debt to the environmental group. This, however, is clearly too simplistic an analysis of debt-for-nature agreements. What is needed is a more thorough understanding of the economic and political effect that these agreements have on each participant. After first reviewing the history and mechanics of debt-for-nature agreements, this paper examines whether the debtor country and environmental group benefits from the debt-for-nature swap compared to the alternative of a straight donation of funds from the environmental group to the developing country, as well as the incentives that commercial banks have to donate, rather than sell, debt to international environmental groups. Finally, what are the future initiatives in debt-for-nature agreements?

History of Debt-for-Nature Swaps

Soon after the onset of the debt crisis in 1982, conservationists began to argue that the large amortization and interest payments made by the highly indebted countries to service their debt were causing irreparable damage to their resource base. According to conservationists, increasing exports to accumulate foreign exchange for debt service put additional pressure on an already fragile resource base, especially since many these countries were already dependent on primary commodity exports for foreign exchange revenue.

Thomas Lovejoy, then vice president of science for the World Wildlife Foundation, wrote an article for the New York Times in 1984 that is deemed as the catalyst for the debt-for-nature concept. Lovejoy advocated that conservation groups should use the debt-equity swap mechanism to raise local currency. In 1987, Conservation International--a international environmental non-profit organization based in the United States--and Bolivia signed the first debt-for-nature agreement. Since then, debt-for-nature agreements have been reached in Costa Rica, Ecuador, and the

Philippines.

The Mechanics of Debt-for-Nature Swaps

In a typical debt-for-nature swap, an international environmental non-profit group uses donated funds to purchase, through a financial intermediary, the debtor country's external debt on the secondary market at a steep discount from the face value of the obligation (referred to as the "secondary market value"). (On rare occasions, commercial banks will donate the debt instrument to the environmental group directly, thereby saving the group the cost of purchasing the debt on the secondary market.) The international environmental group and the debtor country usually then exchange the debt instrument at a prearranged discount from the face value of the debt (referred to as the "redemption value"), and the country issues a domestic currency instrument that will be used by the local environmental group to fund the agreed upon environmental projects. In addition, the debtor country and the international environmental group will sometimes (for example, Bolivia) reach agreements that stipulate development restrictions on protected areas in the debtor country.

The secondary market value of the debt purchased by the environmental group is always at least equal to or less than the redemption value offered by the debtor country, thereby allowing the international environmental group to "leverage" its original donation and supply the local groups with a larger amount of currency than would be available from a straight donation. The difference between secondary market value and the redemption value can be considered the implicit subsidy amount paid by the debtor country to the environmental group. It reflects the amount of the secondary market discount not captured by the country, assuming that the secondary market price somewhat reflects the true price of the debt.

Debt-for-Nature Transactions

As shown in table 1, the total amount of debt (face value) converted in eight debt-for-nature swaps has reached only $79 million as of mid-1989. This is significantly less than other transactions in the secondary market for developing-country loans, which reached a level of $42 billion in 1988 (Debt and International Finance Division Quarterly Review, March 1989). Of the four countries who have debt-for-nature programs (Bolivia, Costa Rica, Ecuador, Philippines), Costa Rica has been the most active, retiring over $68 million (face value) of debt.

Table 1. Debt-for-Nature Transactions.

Country	Date	Cost[1]	Face Value[2]	Local Currency[3]	Organization[4]
Bolivia	7/87	$100,000	$650,000	$250,000	CI
Ecuador	12/87	$354,000	$1,000,000	$1,000,000	WWF
Costa Rica	2/88	$891,000	$5,400,000[5]	$4,050,000	NPF
Costa Rica[6]	6/88	$5,000,000	$33,000,000	$11,000,000	Netherlands
Costa Rica	6/88	$3,500,000	$24,500,000	$17,000,000	Sweden
Philippines	1/89	$200,000	$390,000	$390,000	WWF
Costa Rica	1/89	$784,000	$5,600,000	$1,680,000	TNC
Ecuador	4/89	$1,068,750	$9,000,000	$9,000,000	WWF/TNC

Notes:

1. $US expenditure by environmental groups or governments to purchase the debt on the secondary market.

2. $US face value of the debtor country's external obligations purchased by the environmental groups or governments on the secondary market.

3. $US equivalent of local currency (either in "environmental" bonds or currency) instruments issued by the debtor government in exchange for its external obligations. For "environmental" bonds, this does not include the interest earned over the life of the bonds.

4. WWF is the World Wildlife Fund; TNC is the Nature Conservancy; NPF is the National Park Foundation of Costa Rica; CI is Conservation International

5. Includes $250,000 in debt donated by Fleet National Bank of Rhode Island.

6. According to Dutch officials, the 70 percent of the $33 million ($23 million) was a straight donation of debt to the Costa Rican government, while the remaining 30 percent ($10 million) was converted into local currency bonds at full face value.

Source: Nature Conservancy and assorted newspaper reports.

The details of each debt-for-nature swap can be found in appendix 1. Some of the more interesting points of the agreements are as follows:

* The first debt-for-nature agreement (Bolivia) was the only one in which land was set aside, and development restrictions adopted, as a result of the agreement. This deal was extremely controversial at first, as many Bolivians thought that the country had relinquished sovereignty to the international environmental group. There is, however, no transfer of land ownership, and development decisions are not based on agreements between the local environmental groups, the government, and the regional population. The Bolivian government has been slow in dispersing the local currency funds, and controversies have arisen over the development use of the buffer areas.

* Costa Rica has had the most extensive debt-for-nature program, and was the first country to involve creditor governments (Swedish and the Dutch) in debt-for-nature programs. [Note: Sweden and the Dutch government did not use their own official debt in the

transaction; they purchased commercial bank debt on the secondary market.] After seeing the secondary market price of their debt fall over the last few years, the Costa Rican government has lowered their redemption rate from 70 to 30 percent of face value, thus reducing the implicit subsidy amount paid to the international environmental groups.

* In its two debt-for-nature agreements, Ecuador has redeemed their debt at full face value, granting the largest possible subsidy. Ecuador, however, has offset this large implicit subsidy in part by redeeming its debt at an exchange rate considerably less than market rate, and issuing domestic "environmental" bonds that have (ex post) interest rates lower than the inflation rate.

Who Benefits?

Debt-for-nature swaps are often described as deals "where everyone benefits." This is not necessarily true. This section examines the costs and benefits of debt-for-nature swaps for the three major participants: commercial banks, international environmental groups, and the debtor countries.

Commercial Banks

So far, commercial banks involvement in debt-for-nature swaps have been mainly limited to selling sovereign debt to international conservation groups, or acting as their financial intermediaries. Thus, the banks' role in debt-for-nature swaps have been similar to their role in debt-for-equity swaps; they are willing to supply debt at the secondary market price to any buyer.

Banks have, however, reduced their commission on some of the debt-for-nature swaps. Environmental groups have also been trying to convince banks to donate their debt, thus saving them the cost of purchasing the debt on the secondary market. Despite some recent regulatory changes (such as IRS ruling 87-124, which allows banks to deduct the full face value of the contribution, not just its market value), commercial banks still have little incentive to donate their debt. Currently, only Fleet National Bank of Rhode Island has donated debt for a debt-for-nature swap ($250,000 in the first Costa Rican swap). Even in this case, the bank decided to write-down the debt, thereby receiving a tax deduction on the full amount, rather than risk the financial and regulatory implications of a straight donation of debt.

Donating debt. The key to any significant expansion of debt-for-nature swaps lies in the financial and regulatory incentives for banks to donate their debt. In hope of giving banks incentive to donate their debt, the IRS issued regulation 87-124 in 1988. Before this regulation, a bank donating debt to a non-profit group could only take a tax deduction on the "fair" market value of the donation. Facing Congressional action on this issue, in 1988 the IRS established regulation 87-124. This regulation allows banks, when donating debt, to recognize a loss equal to the difference between the face value of the debt and the fair market value of the debt, and take a charitable deduction equal to the fair market value of the debt. Thus under this ruling, the banks can deduct the full face value of the debt upon donation--not just its fair market value.

It was hoped that this regulation would increase banks' willingness to donate debt for debt-for-nature swaps. But much of the incentive to donate debt is reduced if the difference between the face value of the debt and the fair market value of the debt (the conversion discount) must be treated as a loss and charged against the developing-country loan loss reserve for regulatory purposes. Currently, debt used in debt-for-equity swaps is treated in this manner, and the Securities and Exchange Commission may treat donated debt the same way. Banks are particularly reluctant to record a loss against their developing-country loan-loss reserves as evidenced by money-center banks' unwillingness to trade much of their own debt on the secondary market.

Further obfuscating an already complex tax and regulatory environment is a recent IRS ruling that restricts banks from deducting foreign loan losses from their domestic income. Previously, banks have deducted foreign loan losses from domestic income, thereby protecting their level of foreign loan income. Now, however, foreign loan losses must be apportioned between foreign and domestic income based on the bank's ratio of foreign to total loans. The level of foreign loan income is important because the IRS allows banks to reduce their U.S. taxes dollar-for-dollar by the amount of foreign tax credits (taxes paid to foreign governments). A reduction in the foreign income reduces the amount of foreign tax credits available to the bank. Although this clearly has an impact far beyond the treatment of charitable debt, this ruling could limit bank's incentive to donate debt under 87-

Donate, write-down, or sell? Banks essentially have four options in handling their debt: hold, donate, write-down, or sell. Environmental groups, in seeking debt for donations, are essentially competing against the last two options. All of these options are subject to complex tax and regulatory implications. Both donating the debt and writing off the debt allow the banks to take a tax deduction for the full face value of the debt (that is, the tax rate * face value of the debt). But selling the debt at the secondary market price, and getting a tax deduction for the loss (on the conversion discount), will always yield the bank more, as shown by the following equation.

$$p + (1-p)t > t \quad \text{when } p,t > 0$$

where:

p = secondary market price of the debt, and

t = marginal tax rate.

Benefits and costs to banks. Environmental groups argue that banks receive two major benefits from debt-for-nature swaps; banks can both dispose of their risky debt, and improve their relationships with highly-indebted developing countries. Swaps are also good for the bank's reputation, especially with the increasing importance of environmental issues in developed countries. Environmental groups also argue that developing countries, by increasing their future economic potential through sustainable development policies, can also become better clients for the banks in the long run.

As long as banks are selling--and not donating--debt they experience the same costs that are normally present in any secondary market transaction. However, donating debt may result in certain costs. As shown earlier, it is more profitable, from the bank perspective, to sell the debt on the secondary market than to donate the debt. If the bank is carrying the debt at 100 percent of face value, donating the debt for tax purposes could contaminate the bank's portfolio, forcing it to increase its provisions against similar type loans. Finally, donating debt for debt-for-nature swaps may put additional pressure on banks to forgive other country obligations, and would therefore be unpopular with the bank's shareholders.

Environmental Groups

International environmental groups clearly benefit from debt-for-nature swaps. By receiving more in local currency from the debt swap than they pay for the debt instrument, they can "leverage" the original donation and supply local environmental groups with additional funds. Unless the debtor country redeems the debt at the same discount that the environmental group purchased the instrument, the swap will result in more money than in a straight donation. The debt-for-nature "concept" has also increased the profile of environmental groups, as well as their ability to raise funds for environmental protection.

Finally, prior to the debt-for-nature concept, environmental groups had little or no direct contact with either commercial banks or debt countries' finance ministers. Debt-for-nature swaps, however, have entailed intense negotiations between all three groups, leading to a network of relationships that may prove valuable to international environmental groups beyond simply debt-for-nature agreements.

There are some costs in participating in debt-for-nature agreements for international environmental groups. One of the largest costs to the environmental groups is the amount of time and staff resources it takes to finalize a debt-for-nature agreement. There are many complex steps involved in an agreement, from conceiving of the idea, meeting with the country, organizing donors, finding a financial intermediary, purchasing the debt, finalizing the swap arrangement, and overseeing the implementation. Problems also arise in determining which, and how much, local environmental groups should receive of the local currency funds. As in a straight donation of funds, questions also arise regarding the ultimate influence the donor (the international environmental group) has on the expenditure of the funds. Finally, in the United States, the IRS holds the non-profit group responsible for the expenditure of donated funds.

The environmental groups face a decision: would they get benefit more from a straight donation or a debt-for-nature swap. At first glance, the answer may seem straightforward--a debt-for--nature swap. But, this may not necessarily be true. The break even point for the environmental groups is when the "leveraged" amount received from the swap is equal to the marginal cost of that particular debt-for-nature agreement. The closer the debtor country comes to capturing all of the discount on the secondary market (such as in Costa Rica), the lower is the leveraged amount from the debt-for-nature swap, and the higher probability that the costs of arranging the swap will outweigh the benefits of increased local currency.

Second, some countries exchange the debt at the official exchange rate, often for considerably less local currency units than the parallel market exchange rate (for example, for each dollar converted the environmental group could get 5 units of local currency instead of 8 units). Thus, the implicit subsidy in the debt-for-nature swap may be offset by the difference in the parallel and official exchanges rates.

Third, in addition to the local currency funds that the environmental group receives from the swap, some (for example Bolivia) of the debt agreements have put development limitations on the designated protected areas. The benefit of these restrictions to the international environmental group, and whether these restrictions would have occurred outside of the debt-for-nature framework, is difficult to determine and hard to incorporate in a simple cost analysis.

Fourth, as cited earlier, a debt-for-nature agreement may be more costly than a straight donation to the debtor country because of the number of steps involved in finalizing the agreement.

Finally, the subsidy implicit in the debt-for-nature swap, that is the difference between the redemption and secondary market value of the debt, may be offset to a degree by the differential between the interest yield on a domestic "environmental bond" and a comparable dollar dominated instrument that could be purchased through donated funds. In some of these countries (such as Costa Rica and Ecuador), the environmental bonds issued as a result of the debt-for-nature swap have yielded nominal interest rates lower than the inflation rate. [In Costa Rica, the bonds have yielded interest rates of 15 percent with an inflation of 25 percent, and in Ecuador interest on the bonds were 35 percent with inflation rates of 86 percent, despite the bonds being "tied" to market rates (December to December 1987-88).]

The bonds are generally nontransferable, with a fixed interest rate over at least a four year time horizon; high inflation and a depreciating domestic currency could make a dollar-denominated instrument more attractive. In addition, delays by the debtor country in releasing the funds (such as in the Bolivia swap) results in opportunity costs for the international environmental group, which could have been earning interest on a dollar-denominated instrument in the interim period.

<u>The Debtor Country</u>

The costs and benefits of debt-for-nature swaps to the debtor country are complex. There is an extensive literature on whether it makes sense for debtor countries to participate in buybacks and debt-for-equity swaps, and many of these insights directly apply to debt-for-nature agreements.

<u>Balance of payments.</u> First, it helps to contrast debt-for-nature swaps with its more common relative--debt-for-equity swaps (it is common to hear debt-for-nature swaps referred to as the "son" of

debt-for-equity swaps). These two types of swaps have different effects on the country's external accounts. In a debt-for-equity swap, the stock of external liabilities is reduced by the discount captured by the debtor country. From a balance-of-payments perspective, a debt-for-equity swap involves: (1) a loan repayment (outflow) in the capital account equal to the redemption (market) value of the debt, and (2) foreign direct investment (inflow) equal to the value of the newly created equity instrument. From a long-term investment income flow perspective, a reduction of the country's debt service payments through the retirement of the external obligation is offset (to a degree) by an increase in profit remittances from the direct foreign investment. [Note, however, that debt-for-equity swaps typically prohibit profit remittances during the first five or ten years.]

The effect of a debt-for-nature swap on the external account is slightly different than in a debt-for-equity swap. In a debt-for-nature swap, the stock of external liabilities is reduced by the whole face value of the debt, since their is no concomitant creation of an equity instrument. From a balance-of-payments perspective, a debt-for-nature swap involves (1) a loan repayment (outflow) in the capital account equal to the redemption (market) value of the debt, and (2) an unrequited transfer (inflow, current account) equal to the value of the newly created instrument. From a long-term investment-income flow perspective, there is no outflow of profit remittances to offset the reduction in debt service payments as in a debt-for-equity agreement.

Economic impact of swaps. Debt-for-nature consists essentially of two steps: a buyback of debt, and an issuance of a local currency instrument. Much of the criticism of debt buybacks apply equally to debt-for-nature agreements. Bulow and Rogoff (1988) argue that, from a debtor country perspective, buybacks are a mistake for two reasons: (1) when countries purchase debt at the market price, they are paying "average" debt prices to retire "marginal" debt; and (2) that the collateral used by sovereign debtors (unlike domestic debt where all collateral is seized upon default) can never be fully seized by the creditor government. Therefore, there is less reason for the debtor country (compared to the domestic borrower) to buyback debt, as the debtor country has less to lose in the case of default. Using this standard, debt-for-nature swaps are even worse than straight buybacks, since the debtor country does not even capture the full secondary market discount on its debt.

Other economists argue that the subsidization inherent in debt-for-equity swaps makes sense only as long as the direct foreign investment would not otherwise have occurred. It is possible that this logic could be extended to debt-for-nature swaps; that is, that the subsidization inherent in debt-for-nature swaps would make sense only if the donation would not otherwise have occurred.

Donation versus swap. Is a country better of receiving a straight donation or participating in a debt-for-nature swap? If we assume that the donation would occur even without the debt-for-nature program (probably a generous assumption), the debtor country is clearly better off receiving a straight donation.

In a straight donation of funds, the debtor country has only a limited role in the transaction (and only when the country has a fixed exchanged rate). Looking at the external balance, the country receives an inflow of foreign exchange. The effect of a donation on the Central Bank account balance is shown in table 2. In a floating exchange regime, the conversion of foreign exchange into domestic currency occurs in the financial markets, and the exchange rate adjusts. There is no effect on the Central Bank account balance.

Table 2. Central Bank Accounts

Straight Donation		Debt-for-Nature	
Assets	Liabilities	Assets	Liabilities
(1) F. Exchange +	(1) Currency +		(3) Currency +
	(2) Currency -		(3) External Debt -
	(2) Bonds +		(4) External Debt -
			(4) Bonds +

Many of these countries, however, have a fixed exchange rate regime. In a fixed exchange rate regime, the Central Bank would experience an increase in its foreign exchange assets and domestic currency liabilities (transaction 1). The bank may or may not want to sterilize the monetary impact of the exchange. If the Central Bank does not sterilize, the increase in domestic currency in a donation will be usually be less than the increase in local currency in a debt-for-nature swap, because there is no implicit subsidization by the debtor country in the straight donation case. [Note, however, that in most debt-for-nature swaps the debtor country issues environmental bonds and not an equivalent amount of local currency.]

If the Central Bank does decide to sterilize the monetary effect of the foreign exchange inflow (transaction 2), and issues bonds at competitive market rates, the country could face higher expenditures than in issuing environmental bonds from a debt-for-nature swap. In many cases (Costa Rica, Ecuador) the nominal interest rate on the nontransferable "environmental" bonds have been lower than the rate of inflation, resulting (ex post) in negative real interest rates.

In a debt-for-nature-swap, however, the country receives no foreign exchange inflow. Instead, it is given the opportunity to retire part of its external debt, on which it may or may not be making current payments. If the country is making any payments on the debt, it is likely to be only interest--not principal--payments since the debt is trading at less than face value on the secondary market.

As table 2 shows, in a debt-for-nature swap the Central Bank either exchanges the external debt (after marking it to market value) for domestic currency (transaction 3), or issues a domestic bond at the agreed upon terms (transaction 4). Transactions 3 and 4--unlike transaction 1--involve an exchange of one external type of liability for a domestic liability. But in many of the highly indebted countries, it is the internal balance that is the most binding; the debt-for-nature swap, unlike a straight donation, can clearly worsen the fiscal situation if the expenditures on the domestic bonds exceed the payments on the external debt that is exchanged in the swap.

Benefits to the debtor country. Debt-for-nature swaps are said to benefit the debtor country because it reduces their external debt. As has been argued by numerous economists, reducing the debt overhang may result in efficiency gains for the country. According to this argument, because of the "overhang" of debt, investments that are often efficient from an economic perspective--that is, in which the marginal product of capital is greater than the cost (interest rate) of external borrowing (LIBOR plus some risk premium)--are not undertaken because the return from the investment will be extracted by the creditor for debt service payments. In this situation, reducing the level of debt is beneficial to the country. In addition, unlike a debt-for-equity swap, the debt-for-nature expenditures benefit the debtor country's residents.

Costs to the debtor country. The implicit subsidization of the debt-for-nature swaps, the inflationary impact, and the sovereignty issue are often described as costs to debtor countries. Debtor countries have scarce resources, and expenditures on debt-for-nature swaps may reduce the amount of resources available for other expenditures. To the extent that debt-for-nature expenditures simply replace normal budget expenditures for environmental protection, there is no implicit tradeoff or cost to the government. However, this is not normally the case, as debt-for-nature swaps increase government expenditures on environmental protection over previous levels, potentially reducing expenditures for other--as equally important--programs.

Debt-for-nature swaps appear to have minimal inflationary impact. Most of the debt-for-nature swaps have involved the issuance of environmental bonds and not a lump-sum disbursement of local currency. As shown in table 2, issuing of environmental bonds (transaction 4) has no immediate effect on domestic currency; it involves the exchange of an external debt instrument for an internal debt instrument. If the expenditures on the debt-for-nature swap simply replaces normal budgetary expenditures on the environment, it is not inflationary. [That is, if the debt-for-nature domestic bond was simply a replacement for a domestic bond that would have been issued anyway to cover similar environmental expenditures; otherwise, the issuance of a new bond will eventually lead to additional expenditures.] In addition, the bonds are not inflationary to the extent that their payments are less than or equal to the equivalent payments made on the external debt instrument.

Perhaps the most controversial aspect of debt-for-nature swaps is the possibility that the swaps may result in the debtor country relinquishing aspects of its sovereignty to the international environmental group. But there has never been a single debt-for-nature swap that resulted in a transfer of land ownership from a debtor country to an international environmental group. In fact, only in the Bolivia swap was additional land (the "buffer" areas) set aside and development restrictions adopted to protect these areas. The rest of the swaps have resulted only in local currency instruments designed to fund local environmental groups, and not in creating newly protected areas with specific development limitations.

New Initiatives in Debt-for-Nature Swaps

Official Debt

So far, debt-for-nature swaps have involved only commercial bank debt traded on the secondary market. Unable to get banks to donate debt for debt-for-nature swaps, environmental groups are trying to increase the available pool of debt for debt-for-nature swaps by convincing official creditors to allow their debt to be used in debt-for-nature swaps. Such environmental groups as Nature Conservancy and World Wildlife Fund have been lobbying the U.S. government (both Congress and the Executive Branch) to donate official debt for debt-for-nature or debt-for-development swaps. In the United States, one of the major obstacles in getting the government to donate its debt to the environmental groups is the budgetary impact of the donation. It is still not clear how the donation (or forgiveness) would be scored against the budget; that is, whether a loss of revenue for the government would occur, and if so, how large.

Much of the interest in using official debt for debt-for-development swaps first began as a result of the 1988 Toronto Economic Summit, in which the G-7 countries established guidelines that allowed Paris Club Creditors to forgive debt to the poorest of the Sub-Saharan countries. One of three options given to Paris Club creditors was to forgive up to one-third of the debt of the developing country (with the other two being extended maturities and lower interest rates). France has generally chosen the first option, while the United States (until July 1989) has been reluctant to forgive debt.

Creditor governments' willingness to forgive debt for low-income African countries may open the door to donating debt to environmental groups for debt-for-nature swaps. However, debtor countries are clearly better off having their debt forgiven by creditor governments than buying back their debt through debt-for-nature agreements. Thus, there would be little incentive for debtor countries to participate in debt-for-nature agreements that used official debt if a large amount of their official debt was being forgiven through other channels.

Instead of donating official debt to the international environmental group for debt-for-nature swaps, creditor governments could themselves explicitly link debt forgiveness to a range of policy reforms--such as environmental protection--in debtor countries. If the debtor country compares such an arrangement to a debt-for-nature swap done through an international environmental group, the benefits of not having to issue a local currency instrument (necessary in a debt-for-nature swap) would have to weighed against the costs of agreeing to the creditor country's conditionality.

However, debtor countries (especially Brazil) have been sensitive to international criticism of their environmental policies in the past, and such a direct linkage of debt forgiveness to environmental policy reforms by creditor countries would be extremely controversial. Brazil and other countries are already wary of the sovereignty implications of debt-for-nature agreements; a plan linking debt forgiveness to environmental policy reforms could be viewed as an even greater threat to national sovereignty, and invoke charges of neo-colonialist behavior by creditor countries. However, there is seemingly little chance that any of Brazil's official debt will be forgiven.

World Bank and Debt-for-Nature Swaps

There have been a variety of proposals by international environmental groups, the U.S. Congress, and the U.S. Treasury to increase World Bank involvement in debt-for-nature swaps.

Using multilateral debt for debt-for-nature swaps. As with official debt, international environmental groups have been interested in using multilateral debt for debt-for-nature swaps. World Bank debt has never been rescheduled or sold in secondary markets, and Bank officials have repeatedly stated that they are prohibited by charter to use Bank debt for debt-for-nature swaps. But Congressman John Porter, in testimony before the International Development Institutions Subcommittee of the House Banking Committee on May 24, 1989, argued that the World Bank has some flexibility in refinancing or restructuring debt under Article I, Section 4(C) of the bank's Articles of Agreement (Cody, 1988). According to Porter, the World Bank's choice not to reschedule or refinance can be considered more of a policy decision designed to protect the bank's AAA bond rating.

World Bank as a clearing-house for debt-for-nature swaps. In

April 1988, the U.S. Treasury submitted a report to Congress on possible initiatives that could be undertaken by multilateral development banks--specifically the World Bank--to encourage debt-for-nature swaps (U.S. Department of Treasury, 1988). The report recommended a host of measures that the World Bank could adopt to facilitate debt-for-nature agreements. They are as follows:

* Debt-for-nature swaps could be "piggybacked" on World Bank and other multilateral development banks' environmental loans.

* The World Bank serves as a clearinghouse for debt-for-nature swaps, identifying banks interested in donating (or selling) debt, and acting as a source of information for both environmental groups and debtor countries interested in debt-for-nature swaps.

* Establishing a World Bank pilot program for countries that have, or are interested in implementing, a debt-for-nature program. The World Bank could offer technical assistance in the design of the debt-for-nature program.

Enforceability of debt-for-nature agreements. Finally, there has been some discussion in the U.S. Congress about using the World Bank as a means to ensure that debtor countries actually implement the agreed upon covenants arising from the debt-for-nature agreement (House of Representatives Report 100-994, 1988). In general-obligation finance, the cross-default clause assures lenders the same sanction rights in case of a default. In debt-for-equity and debt-for-nature swaps, the owner of the obligation would have to rely on the domestic legal system of the borrower country to enforce its claim. To increase the costs (and thus the likelihood of compliance) for debtor countries that fail to comply with the terms of their debt-for-nature agreement, some international environmental groups would like to make disbursement of new World Bank environmental loans conditional on debtor country's compliance with debt-for-nature covenants.

Conclusion

Of the three participants in debt-for-nature swaps, the international environmental group benefits the most from the swap, as it leverages its original donation amount by the difference between the secondary market value and the redemption value of the debt. As the difference between the redemption and secondary market value declines over time, the costs of the debt-for-nature swap for the environmental group (such as the complexity of the deals, the low real returns on the domestic instrument, and the differences between official and parallel exchange rates) is more likely to offset the "leveraged" amount gained through the debt-for-nature mechanism.

Unless there is further change to the tax and regulatory environment, there is little reason--other than positive publicity--for commercial banks to donate their debt to the international environmental group. Under the current system, commercial banks can always realize more by selling their debt on the secondary market.

The debtor country subsidizes the swap by the difference between the redemption value and secondary market value of the debt. In the economic literature, there is still considerable controversy over whether the debtor country benefits from buying back its debt at the secondary market price--let alone at the higher redemption rate usually offered in debt-for-nature swaps. From a fiscal standpoint, the debt-for-nature swap, unlike a straight donation, can clearly worsen the budgetary situation if the expenditures on the domestic environmental bond exceeds the debt-service payments on the external debt that is exchanged in the swap.

Highly indebted countries must make difficult fiscal choices, usually facing strict constraints of IMF and World Bank fiscal and monetary targets. In a situation of limited financial resources, expenditures on debt-for-nature swaps reduces the resources available to other projects. To the extent that the swap is seen as a costless transaction, and not explicitly accounted for in a country's budget, expenditures on debt-for-nature swaps may reduce resources for even higher priority projects.

Although debt-for-nature (and development) swaps will never significantly reduce the external debt of developing countries, they can sharply increase the funds available to specific projects in the debtor country. If the debtor countries and donors' expenditure priorities are the same, these swaps can be beneficial to the debtor country.

Finally, the future of debt-for-nature and similar swaps may be limited by the Brady Plan's current emphasis on debt reduction. Debt reduction by commercial banks, forgiveness of official debt by creditor countries, and the clear prohibition of using multilateral debt for debt-for-nature swaps reduces both the available supply of debt and much of incentives for debtor countries to participate in debt-for-nature arrangements. A debtor country would clearly prefer to have its debt forgiven than to swap it for a domestic liability created as a result of the debt-for-nature swap.

Appendix 1

Bolivia

In July 1987, Conservation International, using a $100,000 grant from the Frank Weeden foundation, purchased $650,000 of Bolivia's commercial bank debt at roughly 15 cents on the dollar (a discount of 85 percent). In exchange for Conservation International's cancellation of the debt, Bolivia agreed to set aside 3.7 million acres in three conservation areas surrounding the Beni Biosphere in the Amazon basin. In addition, Bolivia agreed to contribute $100,000 in pesos to a $250,000 peso fund established to manage the Beni Reserve area, with the remaining $150,000 being contributed by the U.S. Agency for International Development (AID). The $250,000 fund is to be administered through the Ministry of Agriculture and a local environmental group to be selected by Conservation International.

The Beni Biosphere area consists of forests and grasslands that support over 13 endangered plant and animal species, 500 species of birds, and is home to the nomadic Chimane Indians. The agreement calls for the newly designated areas, all owned by the government, to serve as a buffer zone to the Biosphere area, allowing sustainable development (such as limited logging and farming) in the buffer areas. The 3.7 million acres includes the 2.9 million Chimane forest reserve, as well as the Yacuma Regional Park and the Corbedeni Hydrological basin (800,000 acres). The $250,000 peso environmental fund will be used to support various programs in the Biosphere and buffer areas. The National Academy of Sciences, a Bolivian NGO, is helping to develop the conservation plans for the buffer areas. The Academy also oversees a commission of local officials and 10 non-governmental institutions, such as the Institute of Ecology and the Environmental League (LIDEMA), that are involved in the development of the areas.

There have, however, been delays and problems in the implementation of the agreement. The Bolivian government only as recently as April 1989 made its $100,000 peso contribution to the environmental fund, while a dispute has developed over the use of the "permanent production forest" in the Chimane forest reserve. This area is home to a number of indigenous population groups, one of which includes the Chimane Indians. When the logging concessions were granted by the Bolivian government earlier in the year, the Chimane Indians (far less organized than the other indigenous groups) were not represented. After a series of protests by the Chimane Indians, the Bolivian government suspended the logging concessions pending a governmental review that is to be completed in the next few months.

The amount of the implicit subsidy in the Bolivian swap is not simply the difference between the redemption value and the secondary market value, for the economic value of the "development" rights to the $3.7 million acre buffer area is difficult to estimate. An analysis of the net present value of the various possible development alternatives for the $3.7 billion acres under the debt-for-nature agreement is outside the scope of this project. Looking simply at the amount paid by Conservation International ($100,000 for $650,000 of Debt) and the amount paid by the Bolivian government ($100,000 for $650,000) for the debt, there is no subsidy, as the Bolivian government captures the full secondary market discount.

Costa Rica

Costa Rica's debt-for-nature program is the largest of the current programs. According to Dr. Alvaro Umana Queseda, Costa Rica's Minister of Natural Resources, Energy and Mines, Costa Rica has swapped over $75 million (face value) of debt for $36 million in local currency bonds--a discount of roughly 48 percent. The $75 million figure includes, however, a $10 million debt-equity swap involving a local door-manufacturing industry, which is generally considered as a private debt-for-equity swap. This is included in the $75 million figure because harvesting restrictions were placed on the 5,000 hectares of forest purchased by the manufacturing company from the proceeds of the swap. In addition, Dr. Quesada reports that the Netherlands and Costa Rica agreed to a $33 million (face value) debt-for-nature swap. However, according to Nature Conservancy and Dutch officials, 70 percent of the $33 million was actually a straight donation of debt to the Costa Rica Central Bank, leaving only $10 million (30 percent) in face value actually converted under a debt-for-nature swap. These classification differences could result in a more conservative $45 million figure for Costa Rica's debt-for-nature program.

The Original $5.4 Million Conversion.

In 1987, the Costa Rica's Central Bank, at Dr. Queseda's suggestion, established a debt-fcr-nature program with an initial ceiling of $5.4 million. This $5.4 million figure was surpassed by early 1988. Funds to purchase the debt came from a variety of sources (World Wildlife Foundation, Nature Conservancy, and others), and $891,000 of donated funds were used by the National Park Foundation of Costa Rica to purchase $5.15 million of debt--at 17 cents on the dollar (a discount of 83.5 percent). The remaining $250,000 of debt was donated by Fleet National Bank of Rhode Island.

The Costa Rica government exchanged its debt at 75 percent of face value, offering $4.05 million in local currency (colones) "environmental bonds," that have a 6 year maturity and an average interest rate of 25 percent. The bonds are nontransferable, offer no principal in the first year, and can be used as collateral for additional loans. The implicit subsidy amounts to $3.1 million for the Costa Rican government. Proceeds of the bonds are to be used for the management of Costa Rica's park system. Seeing the secondary market price of its commercial bank debt drop from 30 cents to the low teens, Costa Rica changed its exchange guarantee from 75 percent to 30 percent of face value after the initial $5.4 million program. By reducing its redemption value, Costa Rica captures more of the discount on the secondary market, and limits the implicit subsidy of the swap.

<u>The $33 Million Netherlands Debt-for-Nature Swap.</u>

According to Dr Queseda, in June 1988 the Dutch Government committed 10 million guilders ($5 million) to purchase Costa Rican commercial bank on the secondary market through a designated financial intermediary. The Dutch government purchased almost $33 million (face value) of debt, at a secondary market price of 15 cents on the dollar (a discount of 85 percent). The rest of the terms of the agreement are unclear. According to Dr. Queseda, Costa Rica converted the $33 million at 33 percent of face value (67 percent discount), issuing $11 million worth of colone environmental bonds with an interest rate of 15 percent and 4 year maturity. According to Nature Conservancy and Dutch officials, 70 percent of the $33 million was donated to Costa Rican government (23 million), while the remaining 30 percent (10 million) was converted into local currency bonds at full face value ($10 million of colone bonds). The bonds are to fund reforestation and support local cooperative institutions concerned about the environment. Although the differences in the terms of the agreement result in roughly the same amount of local currency bonds, they result in a different swap figure--$33 million versus $23 million--and implicit subsidy level--of 18 percent versus 85 percent.

The $24.5 Million Swedish Debt-for-Nature Swap.

Around the same time as the Netherlands agreement, Swedish private conservation groups and student groups, lead by Daniel Janzen, raised over $15 million to support environmental protection of Costa Rica's Guanacaste National Park. $3.5 million of that total was used to purchase $24.5 million (face value) of Costa Rican debt at a price of 14 cents on the dollar (a discount of 86 percent). Costa Rica has agreed to exchange the debt at 70 percent of face value (30 percent discount), issuing $17 million worth of colone environmental bonds at 15 percent interest and 4 year maturity. Since it was Sweden's first bilateral aid contribution, and the project was developed during the terms of the original $5.4 million swap facility, Costa Rica offered to exchange the debt at 70 percent of face value, instead of the new official exchange guarantee of 30 percent of face value. Exchanging the debt at 70 percent face value, instead of 30 percent of face value, increases the implicit subsidy by roughly $10 million ($14 million versus $4 million).

The $5.7 Million Nature Conservancy Debt-for-Nature Swap.

In early 1989, the Nature Conservancy, using $784,000 in donated funds and American Express as its financial intermediary, purchased $5.6 million of Costa Rica debt at a secondary market price of 14 cents on the dollar (a discount of 84 percent). Costa Rica exchanged the debt at 30 percent of face value (70 percent discount), issuing $1.7 million of Costa Rican currency bonds. The bonds will yield an average interest rate of 25 percent over 5 years.

Ecuador

Ecuador has had two debt-for-nature agreements. In the first December 1987 agreement, the World Wildlife Foundation, using 354,000 in donated funds, purchased $1 million (face value) of Ecuador's commercial bank debt at a price of 35 cents on the dollar (a discount of 65 percent). Ecuador exchanged the debt at face value, issuing $1 million of Ecuadorian currency bonds at the official exchange rate. (The official exchange rate is considerably less than the floating rate.) The bonds have a nine year maturity, and are linked to market interest rates. Proceeds from the bonds are to be used for park infrastructure improvements, environmental management plans, park personnel training, and educational activities.

Ecuador's second debt-for-nature swap was completed in April 1989. In this swap, the Nature Conservancy, the World Wildlife Foundation, and the Missouri Botanical Gardens used $1.068 million in donated funds to purchase $9 million (face value) of Ecuador's debt at a cost of roughly 12 cents on the dollar (88 percent discount). Ecuador redeemed the debt at 100 percent of face value, with the proceeds from the $9 million worth of local currency bonds going to Fundacion Natura, Ecuador's leading conservation group. Fundacion Natura will use the money to protect Amazonian national parks and reserves.

Philippines

In an agreement reached in June 1988, the World Wildlife Foundation purchased $390,000 (face value) of Philippine debt at a price of 55 cents on the dollar (a 45 percent discount), using $200,000 in donated funds. The Philippine government redeemed the debt at 100 percent of face value, creating an account containing $390,000 worth of local currency. The account will be managed by the Haribon Foundation. Proceeds from the funds will be used for the protection of two parks on Palawan Island, and the development of management plans and infrastructure for other national parks.

References

Bulow, Jeremy and Kenneth Rogoff. 1988. "The Buyback Boondoggle." Brookings Papers on Economic Activity 2.

Cody, Betsy. 1988. "Debt-for-Nature Swaps in Developing Countries: An Overview of Recent Conservation Efforts." CRS Report to Congress. Congressional Research Service, Environment and Natural Resources Policy Division. Washington, D.C.

Lovejoy, Thomas E. 3d. 1984. "Aid Debtor Nations' Ecology." The New York Times. October 4: A31.

Umana, Alvaro. 1987. "Costa Rica Swaps Debt for Trees." Wall Street Journal. March 6.

Umana, Alvaro. 1989. "Debt Relief for Energy Efficiency, Conservation and Sustainability." Paper presented at World Bank in Washington, D.C. May.

U.S. Congress. House. Participation by the United States in a Capital Stock Increase of the International Bank For Reconstruction and Development and a Replenishment of the African Development Fund, and for Other Purposes: Report to Accompany H.R. 4645. 100th Cong., 2nd sess., 1988.

United States Department of Treasury. 1988. "U.S. Department of Treasury Report to Congress on Debt-for-Nature Swaps." April 15.

PRE Working Paper Series

	Title	Author	Date	Contact for paper
WPS373	Are Better-off Households More Unequal or Less Unequal?	Lawrence Haddad Ravi Kanbur	March 1990	J. Sweeney 31021
WPS374	Two Sources of Bias in Standard Partial Equilibrium Trade Models	Samuel Laird Alexander J. Yeats	February 1990	J. Epps 33710
WPS375	Regional Disparities, Targeting, and Poverty in India	Gaurav Datt Martin Ravallion	March 1990	C. Spooner 30464
WPS376	The World Economy in the Mid-1990s: Alternative Patterns of Trade and Growth	Colin I. Bradford, Jr.	March 1990	C. Evangelista 32645
WPS377	Security for Development in a Post-Bipolar World	John Stremlau		
WPS378	How Does the Debt Crisis Affect Investment and Growth? A Neoclassical Growth Model Applied to Mexico	Patricio Arrau	March 1990	S. King-Watson 31047
WPS379	Some Implications of Policy Games for High Inflation Economies	Miguel A. Kiguel Nissan Liviatan	March 1990	R. Luz 39059
WPS380	Techniques for Railway Restructuring	Lee W. Huff Louis S. Thompson	March 1990	S. Shive 33761
WPS381	Trade in Banking Services: Issues for Multilateral Negotiations	Alan Gelb Silvia Sagari	March 1990	W. Pitayatona-karn 37666
WPS382	The Indonesian Vegetable Oils Sector: Modeling the Impact of Policy Changes	Donald F. Larson	March 1990	D. Gustafson 33714
WPS383	On the Relevance of World Agricultural Prices	Yair Mundlak Donald F. Larson	March 1990	D. Gustafson 33714
WPS384	A Review of the Use of the Rational Expectations: Hypothesis in Models of Primary Commodity Prices	Christopher L. Gilbert		
WPS385	The Principles of Targeting	Timothy Besley Ravi Kanbur	March 1990	J. Sweeney 31021
WPS386	Argentina's Labor Markets in an Era of Adjustment	Luis A. Riveros Carlos E. Sanchez	March 1990	R. Luz 39059
WPS387	Productivity and Externalities: Models of Export-Led Growth	Jaime de Melo Sherman Robinson	March 1990	M. Ameal 37947

PRE Working Paper Series

	Title	Author	Date	Contact for paper
WPS388	The Distortionary Effects of Tariff Exemptions in Argentina	Faezeh Foroutan	March 1990	S. Fallon 38009
WPS389	Monetary Cooperation in the CFA Zone	Patrick Honohan		
WPS390	Price and Monetary Convergence in Currency Unions: The Franc and Rand Zones	Patrick Honohan		
WPS391	An Accounting Framework to Assess Wealth Effects of Voluntary Debt Reduction: Some Applications to Latin America	Daniel Oks		
WPS392	Institutional Development at the Sectoral Level: A Cross Sectoral Review of World Bank Projects	Samuel Paul		
WPS393	Debt-for-Nature Swaps	Michael Occhiolini	March 1990	S. King-Watson 31047
WPS394	Threshold Effects in International Lending	Mark M. Spiegel		
WPS395	The Rope and the Box: Gambian Saving Strategies and What They Imply for International Aid in the Sahel	Parker Shipton		
WPS396	Strategic Trade Policy: How New? How Sensible?	Max Corden		
WPS397	Antidumping Regulations or Procartel Law? The EC Chemical Cases	Patrick A. Messerlin		
WPS398	Agricultural Extension for Women Farmers in Africa	Katrine A. Saito C. Jean Weidemann		
WPS399	Macroeconomic Adjustment, Stabilization, and Growth in Reforming Socialist Economies: Analytical and Policy Issues	Andrés Solimano		
WPS400	Macroeconomic Constraints for Medium Term Growth: A Model for Chile	Andrés Solimano		
WPS401	Policing Unfair Imports: The U.S. Example	J. Michael Finger Tracy Murray	March 1990	N. Artis 38010

Annex 535

Y. Nishiyama, "Are Banks Risk-Averse?", *Eastern European Journal*, 2007, pp. 471-490

ARE BANKS RISK-AVERSE?

Yasuo Nishiyama
Pennsylvania State University - Hazleton

INTRODUCTION

Banks typically operate by extending long-term assets (loans) that are funded primarily by short-term liabilities (deposits), thereby exposing themselves to interest-rate risk. In a period of rising market interest rates, for example, such maturity mismatching implies a decline in income and/or net worth because liabilities reprice faster than assets (or interest-rate risk). A recent study [Sierra and Yeager, 2004] shows, however, that banks in general are only moderately liability sensitive, thereby suggesting that the degree of mismatching may be limited. This finding is consistent with the fact that interest-rate risk control measures are in place at banks in order to limit adverse impacts of interest-rate risk [Houpt and Embersit, 1991]. Also, it is consistent with the risk-averse behavior of banks [Niehans and Hewson, 1976; Niehans, 1978].

The primary objective of this paper is to find out empirically banks' risk preferences (whether or not, and to what extent, banks are risk-averse) that underlie duration[1]/maturity matching or mismatching. This study serves three purposes. First, there is only scant empirical evidence for banks' risk preferences (for example, Ratti [1980] and Angelini [2000]).[2] Second, the Federal Reserve System developed a duration-based economic value model that estimates the sensitivity of market-value equity to changes in interest rates for each U.S. commercial bank [Houpt and Embersit, 1991; Wright and Houpt, 1996; Sierra and Yeager, 2004]. The model, a surveillance tool for bank examiners/supervisors, was operationalized in the first quarter of 1998 [Sierra and Yeager, 2004]. At a more fundamental level, however, it is likely to be informative for bank examiners/supervisors to know banks' risk preferences that underlie these sensitivity estimates. Lastly, and most importantly, the paper is closely related to the issue of deposit rate rigidity examined by Neumark and Sharpe [1992] who provide empirical evidence that both the rate on a time deposit (the six-month certificate of deposit or CD) and the rate on a non-time deposit (money market deposit account or MMDA) move sluggishly relative to open market yields. They find that banks in more concentrated markets are slower to adjust these deposit rates upward, but are faster to adjust them downward. Hence, "banks with market power skim off surplus on movements in both directions" [Neumark and Sharpe, 1992, 657]. In addition, the MMDA rate is found to be more sluggish than the CD rate due to their contractual differences.[3] It is this last finding of Neumark and Sharpe [1992] on which this paper throws new light beyond simply contractual differences.

Yasuo Nishiyama: Division of Business and Economics, Pennsylvania State University, 76 University Drive, Hazleton, PA 18202. E-mail: yun2@psu.edu.

To see the relation between this paper and Neumark and Sharpe [1992], consider a typical bank with mismatched durations, $d_A - d_L > 0$[4] (a positive duration gap) where d_A = weighted-average duration (or maturity) of assets and d_L = weighted-average duration (or maturity) of liabilities. In an environment of rising market interest rates, the bank may lengthen the duration of liabilities (deposits) by increasing its relative holdings of longer-term deposits – if it is risk-averse. This strategy requires the bank to raise interest rates on longer-term deposits (for which six-month CDs are used in this paper) above those on short-term deposits (for which MMDAs are used in this paper), thereby increasing the interest rate spread between the two maturities (CDs over MMDAs) while narrowing the duration gap (i.e., duration matching). Given that market interest rates are known to be procyclical [Stock and Watson, 1999], an alternative interpretation of this strategy is that interest rates on longer-term deposits (CDs) are procyclically more flexible than interest rates on short-term deposits (MMDAs) – if the bank is risk-averse – hence providing a new insight beyond contractual differences noted by Neumark and Sharpe [1992]. (The case of falling market interest rates can be symmetrically explained. See Rose [2002]).

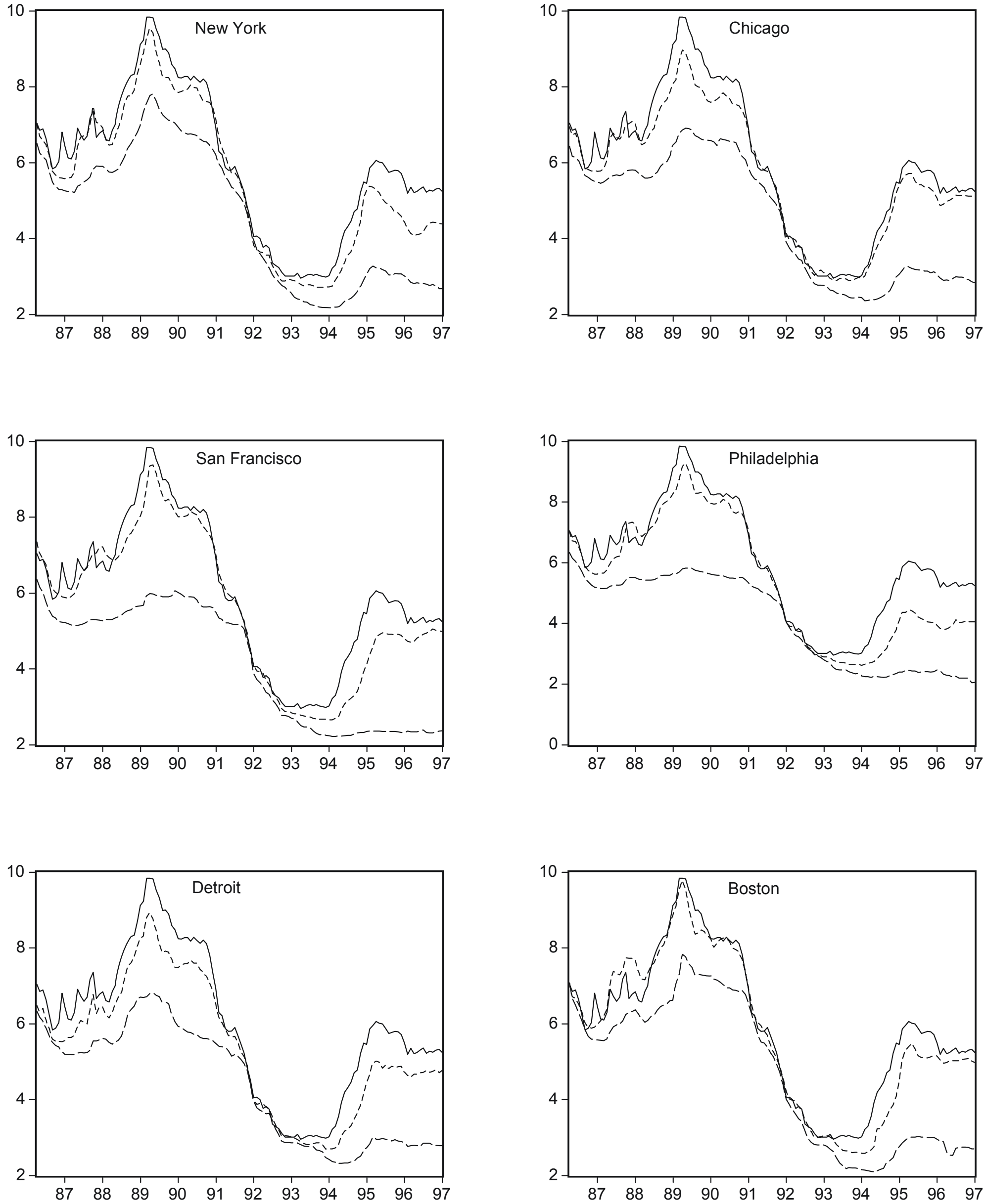
This paper extends Neumark and Sharpe [1992] by advancing two factors to explain why the MMDA rate is more sluggish than the CD rate while the paper's main question (whether or not banks are risk-averse) is also jointly answered. The first factor is duration matching and banks' risk aversion (as explained above). The second factor is the term structure of CD rates (or the yield spread between longer-term CDs and short-term CDs), the details of which are explained below.[5] The main conclusion in this paper based on regressions of selected individual banks is that the average of relative risk aversion (RRA) coefficient estimates falls between 0 and 1 (most likely around 0.2) and hence banks are risk-averse. However, the estimates are very close to zero, suggesting that banks may be nearly risk-neutral.

Figure 1 shows the data used in this paper. It extends the sample period (1983-87) of Neumark and Sharpe [1992], showing the federal funds rate, the rate on MMDAs and the rate on six-month consumer CDs during the 1986-97 period for six cities. (The data of interest rates and the choice of these six cities are explained in Appendix A.) It is clear that the sluggishness of deposit rates (more so in the case of the MMDA rate) relative to market interest rates (the federal funds rate in this paper; the six-month Treasury bill rate in Neumark and Sharpe [1992]) during the sample period of Neumark and Sharpe [1992] has not changed in later years.

The paper proceeds as follows. I develop an intertemporal bank model in the next section and derive two factors that explain the greater flexibility of the CD rate than the MMDA rate. Then, the paper focuses exclusively on the first factor (duration matching and risk aversion) in order to uncover a presumed positive relationship between the degree of risk aversion and the correspondingly desired degree of the CD-MMDA rate spread. Next, the empirical specification that includes both factors is derived, followed by a brief data description, and the estimation results. The final section gives a summary.

FIGURE 1
The Federal Funds Rate, the MMDA Rate and the 6-Month Consumer CD Rate

——— Federal Funds Rate
- - - - 6-Month Consumer CD Rate
– – – – MMDA Rate
Note: Numbers on the vertical axis are in percent.



WHY ARE CD RATES MORE FLEXIBLE THAN MMDA RATES? – TWO FACTORS

The bank model in this paper is an intertemporal version of the well-known Monti-Klein model [Klein, 1971; Monti, 1972] where a representative bank behaves monopolistically, setting both its loan and deposit rates. The bank's asset and liability position at the end of period t is as follows.

Assets:

$L_{2,t-1}$ = two-period loans, booked at t-1, interest paid at t, and repaid with interest at t+1
$L_{1,t}$ = one-period loans, booked at t, and repaid with interest at t+1
$L_{2,t}$ = two-period loans, booked at t, interest paid at t+1, and repaid with interest at t+2
FS_t = federal funds sold
B_t = government securities
R_t = rD_t (total required reserves) where r denotes the reserve requirement ratio (D_t is explained below).

Liabilities and equity capital:

D_t = non-interest-bearing transaction deposits, given exogenously
$D_{m,t}$ = interest-bearing transaction deposits, represented by MMDAs
$D_{c1,t}$ = one-period CDs, issued at t, and mature with interest at t+1
$D_{c2,t-1}$ = two-period CDs, issued at t-1, interest paid at t, and mature with interest at t+1
$D_{c2,t}$ = two-period CDs, issued at t, interest paid at t+1, and mature with interest at t+2
FP_t = federal funds purchased
K_t = equity capital, given exogenously.

The demand function for both one-period and two-period loans (hence omitting the subscripts 1 and 2) is $L_t(\iota_t;Y_t)$ where ι_t denotes the interest rate on loans; Y_t denotes the level of economic activity, given exogenously; $\partial L_t/\partial \iota_t < 0$ and $\partial L_t/\partial Y_t > 0$. For each of MMDAs and CDs, I assume a simple constant-elasticity deposit supply function of the following form (omitting the subscripts): $D = ai^e$ where D and i denote the supply of deposits and the interest rate, respectively; a is a constant ($a > 0$); and e denotes the constant elasticity ($e > 0$). To simplify, it is assumed that the bank holds government securities only to manage liquidity, justifying $B_t = B$ (constant).

The balance sheet constraint is expressed by: $FS_t - FP_t = (1-r)D_t + D_{m,t} + D_{c2,t-1} + D_{c1,t} + D_{c2,t} + K_t - L_{2,t-1} - L_{1,t} - L_{2,t} - B$ where $FS_t - FP_t > 0$ (< 0) indicates the bank's net excess reserves (net reserves shortages) that are lent (borrowed) in the federal funds market. The bank's profit during period t is expressed as

$$\pi_t = \iota_{2,t-2}L_{2,t-2} + \iota_{1,t-1}L_{1,t-1} + \iota_{2,t-1}L_{2,t-1} + i_{f,t}(FS_t - FP_t) + i_{b,t}B - i_{m,t}D_{m,t} - i_{c2,t-2}D_{c2,t-2} - i_{c1,t-1}D_{c1,t-1} - i_{c2,t-1}D_{c2,t-1} - C(TL_t,TD_t) - FC$$

where

$\iota_{n,t-j}$ = interest rate on n-period loans that are booked at t-j (n = 1, 2; j = 1, 2)
$i_{m,t}$ = interest rate on MMDAs
$i_{cn,t-j}$ = interest rate on n-period CDs that are issued at t-j (n = 1, 2; j = 1, 2)
$i_{f,t}$ = federal funds rate, given exogenously
$i_{b,t}$ = yield on government securities, given exogenously
$C(TL_t,TD_t)$ = noninterest cost function with $C_l = \partial C / \partial TL_t > 0$, $TL \equiv L_{2,t-1} + L_{1,t} + L_{2,t}$, $C_d = \partial C / \partial TD_t > 0$, and $TD_t \equiv D_t + D_{m,t} + D_{c1,t} + D_{c2,t-1} + D_{c2,t}$
FC = fixed cost.

The federal funds rate is the source of uncertainty for the bank in the model. The marginal costs (MC) of deposits and loans, C_d and C_l, are assumed to be constant.

Subject to the balance sheet constraint, the bank maximizes the expected value of the time-separable utility function $u(\pi_t)$, $E_t \sum_{s=t}^{\infty} \beta^{s-t} u(\pi_s)$, with respect to time-t loan and deposit rates where π_s denotes period-s profit and β denotes the subjective discount factor. The relevant first order conditions are (* denotes the optimal rate):

(1) $$i_{m,t}^{*} = (1 + e_m^{-1})^{-1}(i_{f,t} - C_d)$$

(2) $$i_{c1,t}^{*} = (1 + e_{c1}^{-1})^{-1}E_t(M_{t+1})^{-1}(i_{f,t} - C_d)$$

(3) $$i_{c2,t}^{*} = (1 + e_{c2}^{-1})^{-1}E_t(M_{t+1})^{-1}(i_{f,t} - C_d)V_t$$

where

e_m , e_{c1} , e_{c2} = elasticity of deposit supply (MMDA, one-period CD, two-period CD, respectively)
C_d = constant MC (noninterest marginal cost)
M_{t+1} = intertemporal marginal rate of substitution (IMRS) of present (time t) for future (time t+1) profit, $M_{t+1} = \beta u'(\pi_{t+1}) / u'(\pi_t)$, and similarly $M_{t+2} = \beta u'(\pi_{t+2}) / u'(\pi_{t+1})$
V_t = $\{1 + [E_t[M_{t+1} (i_{f,t+1} - C_d)] / (i_{f,t} - C_d)]\} / \{1 + [E_t(M_{t+1}M_{t+2}) / E_t(M_{t+1})]\}$.

It is assumed that $i_{f,t} > C_d$.

The paper's main objective is to estimate the spread, $\log(i_{c2,t}^{*}) - \log(i_{m,t}^{*})$, which is related to two factors discussed in the introduction as follows (here assuming $e_m = e_{c1} = e_{c2}$ for simplicity):

(4) $$\log(i_{c2,t}^{*}) - \log(i_{m,t}^{*}) = \underbrace{[\log(i_{c1,t}^{*}) - \log(i_{m,t}^{*})]}_{\text{First factor } = -\log E_t(M_{t+1})} + \underbrace{[\log(i_{c2,t}^{*}) - \log(i_{c1,t}^{*})]}_{\text{Second factor } = \log V_t}.$$

Both the first factor and the second factor account for time variations in the spread. The next section explains how the first factor is related to risk aversion and duration matching. The second factor is related to the economy-wide term structure of interest rates. To see this relationship clearly, assume $M_{t+j} = 1$ (j = 1, 2) which arises under, for example, $\beta = 1$ and risk-neutrality (i.e., a linear utility function). Then, using equations (2) and (3), $i_{c2,t}^{*}$ can be rewritten as

$$\begin{aligned} i_{c2,t}^{*} &= (1 + e_{c2}^{-1})^{-1}\{ [(i_{f,t} + E_t(i_{f,t+1})) / 2] - C_d\} \\ &= (1 + e_{c1}^{-1})(1 + e_{c2}^{-1})^{-1} [(i_{c1,t}^{*} + E_t(i_{c1,t+1}^{*})) / 2]. \end{aligned}$$

A change in expected future monetary policy, $E_t(i_{f,t+1})$,[6] that affects the economy-wide term structure of interest rates (the first line above) also affects the term structure of bank CD rates (the second line above). In general, however, expectations of future monetary policy and IMRSs are intertwined in the V_t term.

In order to avoid notational clutter, a subscript "c" is used throughout below instead of "c1" and "c2." The next section uses "c" for "c1" and the rest of the paper uses "c" for "c2."

RISK AVERSION—THE FIRST FACTOR

As noted above, this subsection limits the model to one-period CDs and one-period loans: assume "c" = "c1" in this section. Therefore the notation used here is as follows: all i_c , e_c and D_c refer to one-period CDs, and all ι and L refer to one-period loans.

Following previous papers [Mehra and Prescott, 1985; Hansen and Jagannathan, 1991; Campbell, 1999; Feldstein and Ranguelova, 2001; and others], I assume that the utility function is isoelastic:

$$u(\pi_t) = (\pi_t^{1-\gamma} - 1)/(1-\gamma)$$

where γ = coefficient of relative risk aversion (RRA).

If Jensen's inequality[7] is ignored for expositional simplicity, i.e., assuming $\log E_t(M_{t+1}) = E_t\log(M_{t+1}) = E_t\log(\beta u'(\pi_{t+1}) / u'(\pi_t))$, then $\log E_t(M_{t+1}) = \log\beta - \gamma E_t\log(\pi_{t+1} / \pi_t)$ and the first term on the right-hand side of equation (4) is expressed as

$$\begin{aligned} \log(i_{c,t}^{*}) - \log(i_{m,t}^{*}) &= - \alpha_c + \alpha_m - \log E_t(M_{t+1}) \\ &= - \alpha_c + \alpha_m - \log\beta + \gamma E_t\log(\pi_{t+1} / \pi_t), \end{aligned} \tag{5}$$

where $\alpha_c = \log(1 + e_c^{-1})$ = constant

$\alpha_m = \log(1 + e_m^{-1})$ = constant.

$\pi_t > 0$ and $\pi_{t+1} > 0$ are assumed. (In practice, $\pi_t < 0$ occurs on rare occasions. See footnote 20.)

If MMDAs are competed for locally while CDs are competed for on a broader geographic basis [Berger and Hannan, 1989; Hannan and Liang, 1993], then the elasticity of deposit supply of CDs is likely to be greater than the elasticity of deposit supply of MMDAs [Hannan and Liang, 1993], i.e., $e_c > e_m$, leading to $-\alpha_c + \alpha_m > 0$ and therefore $\log(i_{c,t}^{*}) - \log(i_{m,t}^{*}) > 0$. This positive and constant spread, however, is not capable of explaining observed time variations in the spread shown in Figure 1. Notice that the spread varies substantially over time and procyclically, suggesting that a satisfactory explanation for these procyclical variations in the spread comes from the last term in equation (5) which differentiates time deposits (CDs) from non-time deposits (MMDAs).

In order to illustrate the main point (that the spread, or the first factor, is related to banks' risk aversion) unambiguously, assume the following: $\pi_t = \pi_{t+1}$ = constant > 0 (initially), $\beta = 1$, $e_c = e_m$, the identical deposit supply function for $D_{m,t}$ and $D_{c,t}$, $FS_t = FP_t$ and $FS_{t+1} = FP_{t+1}$. Furthermore, Y_{t+1} and $i_{f,t+1}$ are assumed constant in order to isolate effects of the procyclical rise in Y_t and $i_{f,t}$. Now, suppose a procyclical deterministic rise in Y_t and $i_{f,t}$[8] ($\Delta Y_t > 0$ and $\Delta i_{f,t} > 0$), thereby causing an increase in loan demand, $\Delta L_t > 0$. To fund this increased loan demand, the bank increases the MMDA rate in order to obtain $\Delta D_{m,t} > 0$ and/or increase the CD rate in order to obtain $\Delta D_{c,t} > 0$, assuming that $\Delta L_t = \Delta D_{c,t} + \Delta D_{m,t} > 0$. Then, it can be shown that the first-order Taylor approximation of equation (5) gives (omitting * for notational simplicity)[9]

$$(6) \quad \gamma = (\pi_t / i_{c,t})(\Delta i_{c,t} - \Delta i_{m,t}) \,/\, [\, (\iota_t + C_l + C_d)\Delta L_t + L_t \Delta\iota_t - D_{m,t}(1 + e_m)(\Delta i_{c,t} - \Delta i_{m,t}) \,],$$

where $\Delta L_t = (\partial L_t / \partial Y_t)\, \Delta Y_t + (\partial L_t / \partial \iota_t)\Delta\iota_t = \Delta D_{c,t} + \Delta D_{m,t}$, $\Delta D_{c,t} = (dD_{c,t} / di_{c,t})\Delta i_{c,t}$, and $\Delta D_{m,t} = (dD_{m,t} / di_{m,t})\Delta i_{m,t}$.

Equation (6) shows that for a given procyclical increase in loan demand $\Delta L_t > 0$, γ and $\Delta i_{c,t} - \Delta i_{m,t}$ are positively related. If a bank is risk-neutral ($\gamma = 0$), then $\Delta i_{c,t} = \Delta i_{m,t}$. In this case, it is optimal for the bank to raise the CD rate and the MMDA rate by the same amount. For a risk-averse bank with $\gamma > 0$, however, it is optimal to raise more funds through new CDs (than through new MMDAs) by raising the CD rate higher than the MMDA rate (i.e., $\Delta i_{c,t} - \Delta i_{m,t} > 0$). Clearly, the greater the degree of risk aversion, the greater the difference $\Delta i_{c,t} - \Delta i_{m,t}$. It implies that the duration gap, defined by $d_{loan} - [(\Delta D_{m,t} / \Delta L_t)\, d_m + (\Delta D_{c,t} / \Delta L_t)\, d_c] = 1 - (\Delta D_{c,t} / \Delta L_t)$, narrows (i.e., duration matching) because $\Delta D_{c,t} / \Delta L_t$ is larger. (d_{loan}, d_m, and d_c are the durations of loans, MMDAs, and CDs, respectively. Since loans and time deposits in this section have simple one-period maturity, their durations and maturities are identical, that is, $d_{loan} = 1$ and $d_c = 1$. $d_m = 0$ because MMDAs are non-time deposits.) Alternatively, it implies that the CD rate is procyclically more flexible than the MMDA rate – if the bank is risk-averse.

A side issue in the above explanation is whether MMDAs and CDs are competed for on a local basis ($e_m < \infty$, $e_c < \infty$) or nationally ($e_m \approx \infty$, $e_c \approx \infty$). It is easily verified by rewriting equation (6) for $\Delta i_{c,t} - \Delta i_{m,t}$ that, even if $\gamma > 0$, $\Delta i_{c,t} = \Delta i_{m,t}$ arises if $e_m = e_c = \infty$. In this case, both the MMDA and CD rates move in tandem with the federal funds rate regardless of the bank's risk preference. Hence, for the explanation above to be persuasive, $e_m < \infty$ and $e_c < \infty$ need to be empirically supported. (The estimation of e_m and e_c is explained below in ESTIMATION RESULTS.)

EMPIRICAL SPECIFICATION AND A PAPER'S LIMITATION[10]

For the rest of the paper, the interest rate on two-period CDs is used: assume "c" = "c2" for the rest of the paper. The two-period CD rate in the theoretical model represents the six-month CD rate in the estimation.

For the second factor in equation (4), I assume the following approximation:

$$\log V_t \approx \mu + \varepsilon_t, \tag{7}$$

where μ = constant (and presumably $\mu > 0$)
ε_t = a stationary stochastic error.

Equation (7), or an approximation of the CD yield spread, is based on (a) an empirical regularity that the Treasury yield curve usually slopes upward [Mishkin, 2001] and (b) Treasury bill spreads are stationary due to cointegration between yields [Stock and Watson, 1988; Hall, Anderson, and Granger, 1992]. They suggest that $\log(V_t)$ may be described by the spread's equilibrium value (μ above which is likely positive according to (a)) plus a stationary stochastic error (ε_t above according to (b)).

Using equation (7), the empirical specification of equation (4) is expressed as

$$\begin{aligned} \log(i_{c,t}^{*}) - \log(i_{m,t}^{*}) &= -\alpha_c + \alpha_m - \log E_t(M_{t+1}) + \log V_t \\ &= -(\alpha_c - \mu) + \alpha_m - \xi_t \end{aligned} \tag{8}$$

where

$$\begin{aligned} \xi_t &\equiv \log E_t(M_{t+1}) - \varepsilon_t \\ &= \log\beta + \log E_t[(\pi_{t+1}/\pi_t)^{-\gamma}] - \varepsilon_t \quad \text{(assuming the isoelastic utility function)} \\ &= \log\beta + E_t\log[(\pi_{t+1}/\pi_t)^{-\gamma}] + (k + \zeta_{t+1}) - \varepsilon_t \quad \text{(assuming conditional lognormality)} \\ &= \text{constant} - \gamma\, E_t\log(\pi_{t+1}/\pi_t) + \text{error} \quad (\text{constant} = \log\beta + k,\ \text{error} = \zeta_{t+1} - \varepsilon_t). \end{aligned} \tag{9}$$

The Jensen's inequality adjustment term on the third line of equation (9), $k + \zeta_{t+1}$, arises as follows. Assume that $(\pi_{t+1}/\pi_t)^{-\gamma}$ is conditionally lognormal, then $\log E_t[(\pi_{t+1}/\pi_t)^{-\gamma}] = E_t\log[(\pi_{t+1}/\pi_t)^{-\gamma}] + (1/2)\text{var}_t[\log(\pi_{t+1}/\pi_t)^{-\gamma}]$. Following Attanasio and Low [2000], assume $(1/2)\text{var}_t[\log(\pi_{t+1}/\pi_t)^{-\gamma}] \approx k + \zeta_{t+1}$ where k is a constant and ζ_{t+1} denotes a random component.

The paper's main objective is to estimate equations (8) and (9), or the CD-MMDA rate spread that ties the more flexible CD rate to the greater degree of risk aversion γ (the first factor) and the CD yield spread $\mu + \varepsilon_t$ (the second factor). It is done in two steps: first, estimate the time series of the unobserved variable ξ_t in equation (8) ("each city's CD – MMDA rate spread" below in ESTIMATION RESULTS) by the Kalman filter[11] and, second, estimate equation (9), or $\hat{\xi}_t$ = constant $- \gamma\, E_t\log(\pi_{t+1}/\pi_t)$ + error where $\hat{\xi}_t$ is the Kalman filter estimate of ξ_t ("individual banks' IMRS equations" below in ESTIMATION RESULTS).

Since the second factor ($\mu + \varepsilon_t$) is subsumed into a constant and an error in equations (8) and (9), it is not treated explicitly as an explanatory variable. This clearly limits the paper's investigation into the second factor. The error, ε_t, may possibly be autocorrelated and/or heteroskedastic, which will be taken into account in the estimation below.

DATA

For estimation, I use six cities' bank rates (MMDA rates and six-month consumer CD rates) that come from Bankrate.com (Bank Rate Monitor, Inc.). The sample period (monthly) is April 1986 (1986:4) through January 1997 (1997:1). The six cities are: 1 = New York, 2 = Chicago, 3 = San Francisco, 4 = Philadelphia, 5 = Detroit, 6 = Boston. Appendix A describes the data in more detail. Each city's MC (noninterest marginal cost of deposits or C_d) is estimated. Appendix B describes the details of the MC estimation.

ESTIMATION RESULTS

The following three sets of equations are estimated.

A. City j – city 1 MMDA rate differential (j = 2, 3, .., 6).
B. Each city's CD – MMDA rate spread or equation (8).
C. Individual banks' IMRS equations or equation (9).

The first set of equations (A) examines the side issue mentioned above, because whether banking markets and/or products are still local or not has been a much debated subject (see, for example, Rhoades [1992]; Radecki [1998]; Heitfield [1999]; Amel and Starr-McCluer [2002]; Heitfield and Prager [2002]). Also, as mentioned above, implied elasticity estimates are derived from the estimation results in order to support the explanation (the first factor) given above. The other two sets of equations (B and C) are explained above in connection with equations (8) and (9).

One complication that must be taken into account in the estimation of the three sets of equations is the rigidity of deposit rates found by Neumark and Sharpe [1992]. Following Neumark and Sharpe [1992], I assume the following partial adjustment model for both the CD and MMDA rates where the subscripts m and c are dropped for notational simplicity:

$$\Delta\log(i_t) = (\lambda + \delta DUM_t)\,[\log(i_t^*) - \log(i_{t-1})] + u_t, \tag{10}$$

where $\Delta\log(i_t) = \log(i_t) - \log(i_{t-1})$
$DUM_t = 1$ if $i_t - i_{t-1} \geq 0$ and 0 otherwise
λ = downward adjustment speed ($\lambda > 0$)
$\lambda + \delta$ = upward adjustment speed (presumably $\delta < 0$).

Analogous to Neumark and Sharpe [1992], a random error u_t is added to the model. λ represents the degree of interest rate rigidity: the lower its value, the more rigid the interest rate is, reflecting banks' greater reluctance to adjust their interest rates. In addition, equation (10) takes account of asymmetric rigidity: if the rate is adjusted more slowly upward than downward, then $\delta < 0$.[12]

A. City j - City 1 MMDA Rate Differential (j = 2, 3, ... , 6)

$$(11)\quad \Delta\log(i_{j,t}) - \Delta\log(i_{1,t}) = (\lambda_j + \delta_j DUM_{j,t})[\log(i_{j,t}^*) - \log(i_{j,t-1})] - (\lambda_1 + \delta_1 DUM_{1,t})[\log(i_{1,t}^*) - \log(i_{1,t-1})] + \text{error}$$

where $i_{j,t}, i_{j,t}^*$ = city j's MMDA rate (j = 1, 2, 3, .., 6), omitting the subscript m
$\log(i_{j,t}^*) = -\alpha_j + \log(i_{f,t} - C_{d,j})$ (j = 1, 2, 3, .., 6)
$\alpha_j = \log(1 + e_j^{-1})$ (j = 1, 2, 3, .., 6)
e_j = city j's MMDA supply elasticity
$C_{d,j}$ = city j's MC (noninterest marginal cost) (j = 1, 2, ..., 6)
error $= u_{j,t} - u_{1,t}$ (j = 2, 3, .., 6).

If MMDAs are local products, then the differential (the left-hand side of equation (11)) is characterized not by random variations but by local factors such as significant λ_j, δ_j, λ_1 and δ_1 (the right-hand side). The implied elasticity e_j is derived from the α_j estimate. A system of five equations (j = 2, 3,..., 6), nonlinear in the parameters and with cross-equation restrictions (α_1, λ_1 and δ_1 are the same across equations), is estimated by the method of SUR (seemingly unrelated regression).

The nonlinear SUR estimation results are shown in Table 1. (The details of the estimation procedure are available from the author upon request.) First, all parameter estimates are significant at the 0.1 percent level (except for one case where the estimate is significant at the 1 percent level) with the expected signs. Second, the statistical significance of all dummy variables bears out the finding of Neumark and Sharpe [1992] about the faster downward speed of adjustment.[13] Third, since changes in MMDA rate differentials between cities depend significantly on local factors (α_j's and λ_j's) and, also, the implied MMDA rate elasticity estimates range from 0.42 (Philadelphia) to 1.16 (Chicago), MMDAs are clearly not competed for at the national level, consistent with Berger and Hannan [1989] and Hannan and Liang [1993].

B. Each City's CD - MMDA Rate Spread or Equation (8) (Modified Based on Equation (10))

$$(12)\quad \Delta\log(i_{c,t}) - \Delta\log(i_{m,t}) = (\lambda_c + \delta_c DUM_{c,t})[\log(i_{c,t}^*) - \log(i_{c,t-1})] - (\lambda_m + \delta_m DUM_{m,t})[\log(i_{m,t}^*) - \log(i_{m,t-1})]$$

where $DUM_{c,t} = 1$ if $i_{c,t} - i_{c,t-1} \geq 0$ and 0 otherwise, similarly for $DUM_{m,t}$
$\log(i_{m,t}^*) = -\alpha_m + \log(i_{f,t} - C_d)$
$\log(i_{c,t}^*) = -(\alpha_c - \mu) - \xi_t + \log(i_{f,t} - C_d)$
$\xi_t = \log E_t(M_{t+1}) - \varepsilon_t$.

The error term u_t in equation (10) is assumed to be the same for both the CD and MMDA equations for the same city and therefore drops out of the above equation. For the unobserved variable ξ_t in equation (12), the following is assumed.[14]

$$(13)\qquad \xi_t = F\xi_{t-1} + v_t$$

where F = constant

v_t = mean-zero Gaussian white noise with $E(v_t v_\tau) > 0$ if t = τ and 0 otherwise.

TABLE 1
City j – City 1 MMDA Rate Differential (j = 2, 3, …, 6), Nonlinear SUR Estimates, Monthly Sample 1986:5-1997:1

Equation (11): $\Delta\log(i_{j,t}) - \Delta\log(i_{1,t}) = (\lambda_j + \delta_j DUM_{j,t})[\log(i_{j,t}{}^*) - \log(i_{j,t\text{-}1})] - (\lambda_1 + \delta_1 DUM_{1,t})[\log(i_{1,t}{}^*) - \log(i_{1,t\text{-}1})]$ + error,

where $\Delta\log(i_{j,t}) = \log(i_{j,t}) - \log(i_{j,t\text{-}1})$, $i_{j,t}$ = city j's MMDA rate
$\Delta\log(i_{1,t}) = \log(i_{1,t}) - \log(i_{1,t\text{-}1})$, $i_{1,t}$ = New York City MMDA rate
$\text{DUM}_{j,t} = 1$ if $i_{j,t} - i_{j,t\text{-}1} \geq 0$ and 0 otherwise (j = 1,2,…,6)
$\log(i_{j,t}{}^*) = -\alpha_j + \log(i_{f,t} - C_{d,j})$ (j = 1,2,…,6)
$\alpha_j = \log(1 + e_j^{-1})$ (j = 1,2,…,6)
e_j = city j's MMDA supply elasticity
$C_{d,j}$ = city j's noninterest marginal cost (j = 1, 2, …, 6)
(Each city's $C_{d,j}$ estimate is given in Appendix B.)
$i_{f,t}$ = federal funds rate.

	MMDA rate			
	Downward adjustment speed:		**Upward adjustment speed:**	
City	λ_j	δ_j	$\lambda_j + \delta_j$	α_j
New York (j = 1)	0.0549***	–0.0348***	0.0201	0.6545***
	(0.0099)	(0.0067)		(0.1271)
Chicago (j = 2)	0.0543***	–0.0244***	0.0299	0.6233***
	(0.0101)	(0.0051)		(0.1246)
San Francisco (j = 3)	0.0467***	–0.0225**	0.0242	0.8021***
	(0.0089)	(0.0080)		(0.2016)
Philadelphia (j = 4)	0.0232***	–0.0111***	0.0121	1.2255***
	(0.0062)	(0.0030)		(0.3409)
Detroit (j = 5)	0.0381***	–0.0231***	0.0150	0.7894***
	(0.0085)	(0.0056)		(0.1934)
Boston (j = 6)	0.0490***	–0.0347***	0.0143	0.6514***
	(0.0093)	(0.0079)		(0.1539)

Note: Standard errors are in parentheses.
*** Significant at the 0.1 percent level.
** Significant at the 1 percent level.

Equations (12) and (13), together called the state-space model, are estimated by maximum likelihood. The parameter estimates of λ_m, δ_m, and α_m (from the estimation of "city j – city 1 MMDA rate differential") are imposed. The implied elasticity e_c is derived from the α_c estimate. The time series of the unobserved variable ξ_t is estimated by the Kalman filter.

Table 2 shows the maximum likelihood estimates of the state-space model (equations (12) and (13)). (The details of the estimation procedure and identification are available from the author upon request.) The findings are similar to those in Table 1: most of the estimates are significant at the 0.1 percent level with the expected signs and (except for San Francisco) the significant δ_c estimates again bear out asymmetric adjustment. To be consistent with Neumark and Sharpe [1992], CD rates are much less rigid than MMDA rates (the values of λ_c and $\lambda_c + \delta_c$ are much larger than those of MMDA rates).[15]

TABLE 2
Each City's CD – MMDA Rate Spread (State-Space Model), Maximum Likelihood Estimates, Monthly Sample 1986:6-1997:1

Equation (12): $\Delta\log(i_{c,t}) - \Delta\log(i_{m,t}) = (\lambda_c + \delta_c DUM_{c,t})[\log(i_{c,t}{*}) - \log(i_{c,t-1})] - (\lambda_m + \delta_m DUM_{m,t})[\log(i_{m,t}{*}) - \log(i_{m,t-1})]$

Equation (13): $\xi_t = F\xi_{t-1}$ + error

where $\Delta\log(i_{c,t}) = \log(i_{c,t}) - \log(i_{c,t-1})$, $i_{c,t}$ = CD rate
$\Delta\log(i_{m,t}) = \log(i_{m,t}) - \log(i_{m,t-1})$, $i_{m,t}$ = MMDA rate
$DUM_{c,t} = 1$ if $i_{c,t} - i_{c,t-1} \geq 0$ and 0 otherwise, similarly for $DUM_{m,t}$
$\log(i_{c,t}{*}) = -(\alpha_c - \mu) - \xi_t + \log(i_{f,t} - C_d)$
$\log(i_{m,t}{*}) = -\alpha_m + \log(i_{f,t} - C_d)$
$\xi_t \equiv \log E_t(M_{t+1}) - \varepsilon_t$ (See footnote 14.)
M_{t+1} = intertemporal marginal rate of substitution
$i_{f,t}$ = federal funds rate
C_d = noninterest marginal cost.
(Each city's C_d estimate is given in Appendix B.)

Parameters estimated: λ_c, δ_c, $\alpha_c - \mu$, F.
Time series estimated: ξ_t. (The resulting Kalman filter estimates $\hat{\xi}_t$ are used in Table 3.)
Parameter values imposed: λ_m, δ_m, α_m estimates from Table 1.

	CD rate				
	Downward adjustment speed:			Upward adjustment speed:	
City	λ_c	δ_c	$\lambda_c + \delta_c$	$\alpha_c - \mu$	F
New York	0.2331***	–0.0489***	0.1842	0.0723***	0.3876***
	(0.0243)	(0.0081)		(0.0155)	(0.1010)
Chicago	0.2014***	–0.0693***	0.1321	0.0646**	0.5726***
	(0.0256)	(0.0113)		(0.0241)	(0.0737)
San Francisco	0.2153***	–0.0084	0.2069	0.0694***	0.3977***
	(0.0142)	(0.0071)		(0.0129)	(0.0830)
Philadelphia	0.1235***	–0.0151***	0.1084	0.0265	0.5899***
	(0.0188)	(0.0038)		(0.0405)	(0.0636)
Detroit	0.1269***	–0.0430***	0.0839	0.1090**	0.2224*
	(0.0154)	(0.0060)		(0.0348)	(0.0929)
Boston	0.1193***	–0.0546***	0.0647	0.0515	0.2781**
	(0.0191)	(0.0087)		(0.0478)	(0.0830)

Note: Standard errors are in parentheses.
*** Significant at the 0.1 percent level.
** Significant at the 1 percent level.
* Significant at the 5 percent level.

The implied elasticity estimates derived from the α_c estimates are much larger than those of MMDA rates, consistent with the notion that CDs are competed for on a broader geographic basis [Berger and Hannan, 1989; and Hannan and Liang, 1993]. If $\mu = 0$ is assumed, then the implied CD rate elasticity estimates range from 8.68 (Detroit) to 18.92 (Boston), except for Philadelphia (37.23). The implied CD rate elasticity estimates are likely smaller, however, because μ is presumably positive.

Clearly, CDs are not competed for at the national level because these implied elasticity estimates vary widely from city to city, and their values are limited. Hence, the elasticity estimates (safely concluding $e_m < \infty$ and $e_c < \infty$) indeed provide support for the explanation of the first factor given above.

C. Individual Banks' IMRS Equations or Equation (*9*)

Equation (9) is estimated for selected individual banks in each city (Appendix B explains individual banks). Each city's time series estimates $\hat{\xi}_t$, which are obtained from the estimation of "each city's CD – MMDA rate spread" above and are interpreted as those of the city's representative bank, are used for ξ_t in equation (9) for individual banks in the same city. For the variable π_t, I use each individual bank's return on total assets (commonly denoted by ROA, that is, the ratio of net income to total assets) instead of each bank's net income because ROA data take into account mergers and/or acquisitions and/or divestitures while net income data do not.[16]

For unobserved $E_t \log(\pi_{t+1}/\pi_t)$ in equation (9), I assume two different expectation schemes. First, since ROA is likely stationary (see, for example, Bassett and Carlson, [2002, Table A.1]), one way to model expectations of such a stationary process is to assume regressive expectations: $E_t \log(\pi_{t+1}/\pi_t) = -\phi(\log\pi_t - \overline{\log\pi})$ where $\phi > 0$ and $\overline{\log\pi}$ denotes the long-run log(ROA) (for which the sample mean is used below). Second, I assume rational expectations: $\log(\pi_{t+1}/\pi_t) = E_t \log(\pi_{t+1}/\pi_t) + \omega_{t+1}$ where ω_{t+1} denotes an expectation error. Then, the empirical specifications of equation (9) based on regressive and rational expectations are, respectively, as follows.

$$(14) \quad \text{Regressive Expectations: } \hat{\xi}_t = \text{constant} + \gamma\phi\left(\log\pi_t - \overline{\log\pi}\right) + \text{error}$$

$$(15) \quad \text{Rational Expectations: } \hat{\xi}_t = \text{constant} - \gamma\log\left(\pi_{t+1}/\pi_t\right) + \text{error},$$

where constant $= \log\beta + k$

error $= \zeta_{t+1} - \varepsilon_t$ (equation (14)), and $\zeta_{t+1} - \varepsilon_t + \gamma\,\omega_{t+1}$ (equation (15)).

Several clarifications are necessary. First, since time series estimates of ξ_t are monthly while bank profit data are quarterly, simple averaging is used to convert monthly into quarterly series. Second, in actual estimation the regressors in equations (14) and (15) are lagged by one.[17] Third, equation (14) is estimated by OLS and IV (instrumental variable estimation).[18] IV is used because ε_t (possibly influenced by time-varying expectations on future monetary policy) may be correlated with the regressor (expected profit growth).[19] Equation (15) is estimated by IV because the regressor and the expectation error term (ω_{t+1}) are correlated. In addition, the regressor may be correlated with ε_t. Fourth, as indicated in connection with equations (7), (8) and (9), ε_t may possibly be autocorrelated and/or heteroskedastic. Therefore, the heteroskedasticity-autocorrelation consistent covariance matrix estimator [Newey and West, 1987] is used for statistical tests

The results are shown in Table 3.[20] Clearly, ξ_t is significantly associated with expected profit growth at the individual bank level (except for San Francisco) when regressive expectations are assumed. The results in Panel A (OLS estimates) show a

TABLE 3
Estimation Results of the RRA Coefficient (γ) of Individual Banks,[a] Quarterly Sample 1986:III-1997:I

Equation (14): $\hat{\xi}_t = \text{constant} + \gamma\phi\left(\log\pi_t - \overline{\log\pi}\right) + \text{error}$

[Regressive Expectations, $E_t \log(\pi_{t+1}/\pi_t) = -\phi\left(\log\pi_t - \overline{\log\pi}\right)$, are assumed.]

Equation (15): $\hat{\xi}_t = \text{constant} - \gamma\log\left(\pi_{t+1}/\pi_t\right) + \text{error}$,

[Rational expectations, $\log(\pi_{t+1}/\pi_t) = E_t\log(\pi_{t+1}/\pi_t) + \text{error}$, are assumed.]

where $\hat{\xi}_t$ = Kalman filter time-series estimates
π_t = ROA (return on assets)
$\overline{\log\pi}$ = long-run level (the sample mean is used).

Estimation methods: Equation (14) is estimated by OLS and IV (instrumental variable method). Equation (15) is estimated by IV. The instruments used for equation (14) (equation (15)) are four lags of the regressor of equation (15) (equation (14)). The validity of the instruments used is explained in footnote 18.

Note: For the actual estimation, the regressors in equations (14) and (15) are lagged by one (see footnote 17).

Equation (14)	Estimates[b] of $\phi\gamma$ ($\phi > 0$, $\gamma \geq 0$, γ = coefficient of relative risk aversion)					
	Bank 1	**Bank 2**	**Bank 3**	**Bank 4**	**Bank 5**	**Bank 6**
			Panel A: OLS			
New York	0.0283*	0.0221**	–0.0063	0.0336**	–0.0007	0.0255*
	(0.0153)	(0.0108)	(0.0231)	(0.0165)	(0.0271)	(0.0155)
Chicago	0.3208***	0.2123***	0.1665***	0.2534***	0.1790***	
	(0.0492)	(0.0447)	(0.0334)	(0.0482)	(0.0518)	
San Francisco	0.0082	–0.0132	0.0130	–0.0086		
	(0.0253)	(0.0339)	(0.0228)	(0.0092)		
Philadelphia	0.1521***	0.1909**	0.2067***	0.1954**	0.0447**	
	(0.0376)	(0.0774)	(0.0681)	(0.0787)	(0.0211)	
Detroit	0.0890***	0.0248	0.0788**	0.0341*	0.0462*	
	(0.0220)	(0.0275)	(0.0312)	(0.0213)	(0.0257)	
Boston	0.1586***	0.0169**	0.0620	0.0563**		
	(0.0366)	(0.0080)	(0.0393)	(0.0284)		

little stronger evidence than those in Panel B (IV estimates). The finding is consistent with the theoretical interpretation of ξ_t as IMRS. Under the assumption of regressive expectations, the OLS point estimates of $\phi\gamma$ in Panel A that are statistically significant at least at the 10 percent level (two-tailed tests) range from 0.3208 to 0.0169 and their sample average is 0.1196. It implies that, for example, if $\phi = 0.9$ ($\phi = 0.5$), then the sample-average RRA coefficient is $\gamma = 0.1329$ ($\gamma = 0.2392$). Similarly, the IV estimates in Panel B that are statistically significant at least at the 10 percent level range from 0.3937 to 0.0333 and their sample average is 0.1862. If $\phi = 0.9$ ($\phi = 0.5$), then the sample-average RRA coefficient is $\gamma = 0.2069$ ($\gamma = 0.3724$).

Under the assumption of rational expectations, the finding is still consistent, though a little weaker, with the theoretical interpretation of ξ_t as IMRS. The point estimates of the RRA coefficient γ that are statistically significant at least at the 10

TABLE 3 — Continued
Estimation Results of the RRA Coefficient (γ) of Individual Banks,[a] Quarterly Sample 1986:III-1997:I

Equation (14)	Estimates[b] of $\phi\gamma$ ($\phi > 0$, $\gamma \geq 0$, γ = coefficient of relative risk aversion)					
	Bank 1	**Bank 2**	**Bank 3**	**Bank 4**	**Bank 5**	**Bank 6**
	Panel B: IV (Instrumental variable)					
New York	0.0523***	0.0221	0.0333*	0.2194**	–0.0078	0.1072*
	(0.0116)	(0.0153)	(0.0207)	(0.1029)	(0.0355)	(0.0603)
Chicago	0.3091***	0.2718***	0.1888**	0.2673***	0.1287**	
	(0.0574)	(0.1033)	(0.0749)	(0.0789)	(0.0615)	
San Francisco	–0.0440	–0.0878	0.0314	–0.0106		
	(0.0918)	(0.0883)	(0.0322)	(0.0115)		
Philadelphia	0.1236***	0.1754	0.3937*	0.2386	0.2700***	
	(0.0407)	(0.1837)	(0.2315)	(0.1639)	(0.1027)	
Detroit	0.1137***	–0.0101	0.0795	–0.0042	0.0137	
	(0.0434)	(0.0113)	(0.0617)	(0.0244)	(0.0204)	
Boston	0.1643***	0.1505***	–0.0068	0.0271		
	(0.0497)	(0.0544)	(0.0404)	(0.0803)		

Equation (15)	Estimates[b,c] of $-\gamma$ ($\gamma \geq 0$, γ = coefficient of relative risk aversion)					
	Bank 1	**Bank 2**	**Bank 3**	**Bank 4**	**Bank 5**	**Bank 6**
New York	–0.0371*	–0.0225	–0.0975	–0.1601**	0.0179	–0.0352
	(0.0214)	(0.0164)	(0.1974)	(0.0757)	(0.0222)	(0.0861)
Chicago	–0.3733*	–0.9655*	–0.1124	–0.9801	–0.3503	
	(0.1942)	(0.5132)	(0.1294)	(0.7225)	(0.3108)	
San Francisco	0.0141	0.1093	–0.0016	0.0130		
	(0.1097)	(0.0851)	(0.0245)	(0.0128)		
Philadelphia	–0.1455**	–0.5339	1.3239	–0.3089*	–0.2248	
	(0.0677)	(0.5390)	(1.3374)	(0.1804)	(0.4330)	
Detroit	–0.3211	–0.0171	–0.0591	–0.0258	–0.0617	
	(0.2631)	(0.0347)	(0.1221)	(0.0290)	(0.0779)	
Boston	–0.2190***	–0.1162*	–0.0113	–0.1152		
	(0.0458)	(0.0652)	(0.0356)	(0.1112)		

Note: Standard errors are in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.
a Appendix B explains individual banks for each city.
b The heteroskedasticity-autocorrelation consistent covariance matrix estimator is used [Newey and West, 1987].
c Instrumental variable estimation.

percent level (two-tailed tests) range from 0.9655 to 0.0371 (from 0.3733 to 0.0371 if Chicago-Bank 2 is excluded) and their sample average is 0.2907 (0.1943 if Chicago-Bank 2 is excluded).

Based on the estimates in Table 3, the individual banks' RRA coefficients appear to fall between 0 and 1 (most likely around 0.2) and hence banks are risk-averse. However, the estimates in this paper are very close to zero, suggesting that banks may be nearly risk-neutral. The range of the RRA coefficient estimates is consistent with $\gamma \approx 1$, or $\gamma < 2$, or $\gamma < 3$, which economists commonly agree on [Arrow, 1965; Ljungqvist and Sargent, 2000, 258-260; Feldstein and Ranguelova, 2001]. One implication for equation (8) from the finding of near risk-neutrality is that, although the first factor (the $\gamma E_t \log(\pi_{t+1}/\pi_t)$ term) indeed explains the observed relative flexibility of CD rates, its quantitative importance to account for the CD-MMDA rate spread may be limited because $\gamma \approx 0$.[21] This of course does not diminish the importance of the paper's main objective of investigating whether banks are risk-averse or not.

Lastly, it is noted that insignificant results in Table 3 are difficult to interpret because they may arise, even if the theoretical interpretation of ξ_t as IMRS is true, when any of the auxiliary assumptions (such as isoelastic utility and the lognormal distribution) is empirically invalid at the individual bank level.

CONCLUSION

I have analyzed an issue which has received little attention in the literature: whether or not, and to what extent, banks are risk-averse. Based on an intertemporal bank model, I have shown that IMRS (intertemporal marginal rate of substitution), or indirectly the RRA (relative risk aversion) coefficient, explains a fundamental difference between the interest rates on time deposits (CDs) and non-time deposits (MMDAs). In particular, the greater degree of procyclical flexibility in the CD rate (than the MMDA rate) is associated with the greater degree of risk aversion. I have estimated the hypothesized relationship between IMRS and the RRA coefficient at the individual bank level, where the unobservable IMRS in the CD-MMDA rate spread is estimated using the Kalman filter. The individual banks' RRA coefficients appear to fall between 0 and 1 (most likely around 0.2), thereby providing evidence that banks are risk-averse, though close to being risk-neutral.

APPENDIX A

Data

Monthly data for the MMDA rate and the six-month consumer CD rate, April 1986 (1986:4) through January 1997 (1997:1), come from Bankrate.com (Bank Rate Monitor, Inc). which is the same data source used previously by others [Diebold and Sharpe, 1990; Radecki, 1998; Heitfield, 1999]. Longer and consistent time-series data are available for ten major markets. Out of these ten markets, I exclude four markets (Los Angeles, Houston, Dallas and the District of Columbia), leaving six markets (j = 1, 2, … , 6) to be analyzed in this paper: New York (j = 1), Chicago (j = 2), San Francisco (j = 3), Philadelphia (j = 4), Detroit (j = 5), and Boston (j = 6). The out-of-state bank holding companies' deposit shares in the District of Columbia and Texas were, respectively, 58.70 percent and 53.01 percent in June, 1993 [Savage, 1993], suggesting that the District of Columbia, Houston and Dallas do not constitute geographically well-defined local markets for deposits. A close examination of Los Angeles and San Francisco data indicates that these cities' data are practically identical, hence excluding Los Angeles. The sample starts from 1986:4 because the data are not available before that for San Francisco and Boston. The sample ends at 1997:1, covering the period of interstate (and intrastate) banking restrictions that had effectively limited the scope of geographic expansion of banking activities in the United States [Savage, 1987; 1993]. I focus on this period in order to maintain the analysis free from the nationwide banking era that has started effectively in 1997 under the Riegle-Neal Interstate Banking and Branching Efficiency Act of 1994. Each city's deposit rate used in this paper is calculated (by Bankrate.com) as the simple average of the city's ten large institutions' deposit rates (five large banks and five large thrifts) which is interpreted as the deposit rate of a representative (or an average) bank in that city. The monthly federal funds rate data come from DRI/McGraw-Hill (RMFEDFUNDSNS series).

APPENDIX B

MC Estimation

Since monthly deposit rate data are averages of ten large institutions' rates for each city, it is reasonable to base each city's MC estimation on these ten institutions which can be identified in *Bank Rate Monitor* published by Bankrate.com. Because of mergers/acquisions over time and/or incomplete data availability for some banks, each city ends up with only about five banks that have complete data for estimation. The table below shows the names of banks included in the MC estimation and for which equations (14) and (15) are estimated.

The procedure to obtain MC estimates is as follows. First, using 1986:III-1997:I quarterly data (from the Federal Reserve Bank of Chicago BHC database), I estimate the standard translog noninterest cost function with the symmetry and homogeneity restrictions, which is based on Gilligan, Smirlock, and Marshall [1984], for individual banks that were included in the Bankrate.com survey list (below). Second, MC estimates for 1986:III-1997:I of individual banks are derived from the estimated translog cost functions. Third, constant MC for a representative bank for each city is calculated as the average of sample means of (each city's) individual bank's MCs weighted by each bank's 1994 MSA deposit share. Further details are available from the author upon request. The results are: 0.00311 (San Francisco) < 0.00441 (Chicago) < 0.00531 (New York) < 0.00802 (Detroit) < 0.00919 (Boston) < 0.01153 (Philadelphia). (For San Francisco, MC = 0.00311 means that the marginal noninterest operating costs are \$0.00311 per total deposits dollar.)

Banks surveyed by Bankrate.com (Bank Rate Monitor, July 24, 1996)

New York

Chase Manhattan Bank (Bank 1), Bank of New York (Bank 2), Citibank (Bank 3), Emigrant Savings (Bank 4), Green Point Bank (Bank 5), Republic National Bank (Bank 6).

Chicago

Harris Trust & Savings Bank (Bank 1), Northern Trust Bank (Bank 2), First National Bank Chicago (Bank 3), American National B & T (Bank 4), LaSalle National Bank (Bank 5).

San Francisco

Bank of America (Bank 1), Wells Fargo Bank (Bank 2), Sumitomo Bank of California (Bank 3), Union Bank (Bank 4).

Philadelphia

CoreStates Bank (Bank 1), Mellon Bank (Bank 2), Beneficial Mutual Savings Bank (Bank 3), Frankford Bank (Bank 4), Firstrust Savings Bank (Bank 5).

Detroit

NBD Bank (Bank 1), First of America Bank (Bank 2), Michigan National Bank (Bank 3), Huntington Banks of Michigan (Bank 4), Comerica Bank (Bank 5).

Boston

Fleet Bank of Massachusetts (Bank 1), Cambridge Savings Bank (Bank 2), US Trust (Bank 3), PNC Bank New England (Bank 4).

NOTES

I would like to thank Ron Britto, Ed Kokkelenberg and Dick Courtney for their comments, Jeff Perloff and Bent Sorensen for very helpful suggestions, and Yoon-Seok Jee for data assistance. I am grateful to two anonymous referees for their very useful comments and suggestions. Also, I am grateful to Alan Price for his help in preparing the final version of this paper. In order to limit the length, some details are omitted from (and their omissions are indicated in) this paper. The full version of this paper is available from the author upon request.

1. Duration (denoted by d), due to Macaulay [1938], measures the average maturity of a security's stream of future cash flows and is defined by $d \equiv \sum_{t=1}^{T} \left[tCF_t /(1+i)^t \right] / P$ where CF_t denotes the cash flow in period t, i denotes the discount rate, and P denotes the present value of future cash flows of the security. Duration gap management is explained in, for example, Rose [2002].
2. Ratti [1980] shows evidence of banks' risk aversion based on a static stochastic bank model and using 1976-77 pre-deregulation data (i.e., prior to the elimination of Regulation Q interest-rate ceilings). Angelini [2000] also shows evidence of banks' risk aversion based on the finding that Italian banks' intraday interbank operations are more concentrated in early morning hours on settlement days, which is consistent with the risk-averse assumption in his theoretical model.
3. "A price change instituted on CDs affects only marginal accounts – new CDs issued or old ones rolled over – and represents a contractual commitment. In contrast, for MMDAs, a change in price amounts to a repricing of all accounts, and confers no explicit contractual commitment on yields even one week into the future" [Neumark and Sharpe, 1992, 677].
4. More precisely, $d_A - (MVL/MVA)d_L > 0$ where MVL and MVA are the market value of liabilities and the market value of assets, respectively.
5. I thank a referee for pointing out the term structure of interest rates.
6. It is assumed that the federal funds rate is an indicator of monetary policy [Bernanke and Blinder, 1992].
7. $\log E_t(M_{t+1}) > E_t \log(M_{t+1})$.
8. The federal funds rate is known to be procyclical [Stock and Watson, 1999].
9. The first order condition with respect to ι_t is: $\iota_t^* = (1 - e_l^{-1})^{-1} E_t(M_{t+1})^{-1}(i_{f,t} + C_l)$ where $e_l = -(\iota_t/L_t)(\partial L_t / \partial \iota_t)$. Therefore, ι_t^* also changes (in addition to changes in $i_{c,t}^*$ and $i_{m,t}^*$) when $i_{f,t}$ changes.
10. The full version of this paper, available from the author upon request, addresses two additional possible limitations: the absence of the household's decision in this paper, and the assumption of constant MC.
11. The variable ξ_t includes unobserved conditional expectations $E_t(M_{t+1})$. I follow, for example, Fama and Gibbons [1982] and Hamilton [1985] who use the Kalman filter method [Hamilton, 1994] for unobserved conditional expectations.
12. Neumark and Sharpe [1992] primarily focus on deposit rate rigidity measured by the estimate of λ and its determinants, whereas this paper's primary interest (with secondary interest in the λ estimates) is in the optimal deposit rate i_t^* which (together with λ) accounts for the observed sluggishness of the actual deposit rate i_t relative to open market rates (such as $i_{f,t}$).

13. The full version of this paper discusses differences between the estimates of λ in Neumark and Sharpe [1992] and those in this paper.
14. In actual estimation, the state variable is defined as $(\lambda_c + \delta_c DUM_{c,t})\xi_t$ (instead of ξ_t). After λ_c, δ_c and the state variable are estimated, $\hat{\xi}_t$ is derived by $\hat{\xi}_t$ = (state variable estimate) $\left(\hat{\lambda}_c + \hat{\delta}_c DUM_{c,t}\right)^{-1}$ where the hat ^ indicates the estimate.
15. One possible explanation of greater MMDA rate rigidity, not explained in Neumark and Sharpe [1992], is that bank customers holding MMDAs may be less attentive to rate fluctuations than CD holders. Hence, banks may change MMDA rates less frequently. This was pointed out by a referee.
16. Quarterly data of individual banks' net income and total assets come from the Federal Reserve Bank of Chicago BHC database.
17. The time series data of $\hat{\xi}_t$ (the regressand) estimated by the Kalman filter are one-step ahead conditional forecasts of ξ_t, that is, $\hat{\xi}_{t|t-1}$. On the other hand, the regressor is $E_t\log(\pi_{t+1}/\pi_t)$. To match the time subscripts (because, by definition, $\xi_t \equiv \log E_t(M_{t+1}) - \varepsilon_t$), the regressor is lagged by one. (The full version of this paper explains this in a little more detail).
18. For equation (14) (for equation (15)), four lags of the regressor in the other equation, i.e., equation (15) (equation (14)), are used as instruments. For the chosen instruments, I tested the null hypothesis of independence of the instruments and the error term using the Sargan's instrument validity test [Cuthbertson, Hall, and Taylor, 1992] at the 5 percent significance level. For equation (14), only 4 cases out of 29 tests (29 banks) resulted in rejection of the null, suggesting validity of the instruments used. For equation (15), there were 7 rejections (out of 29 tests), suggesting a little weaker, nevertheless likely support of, validity of the instruments used. The instruments used appeared reasonably correlated with the regressor. The average of 58 sample correlations (29 correlations from each of equations (14) and (15)) between the regressor and the instruments was about 0.6. Therefore, the instruments chosen are considered reasonably valid.
19. I thank a referee for pointing out this correlation.
20. The sample period is 1986:III-1997:I for most banks; however, it is shorter for some banks (Bank 4 and Bank 5 of New York; Bank 3 and Bank 5 of Philadelphia) due to only partial availability of net income data. Also, each of the following three banks' samples includes one undefined observation for the regressor (i.e., $\log\pi$ is undefined) due to a non-positive value of π = ROA: Detroit Bank 3 (1995:IV); Detroit Bank 5 (1987:IV); and Boston Bank 4 (1993:III). Based on Greene [1993, 273-276], I drop this one observation from each bank's sample.
21. I thank a referee for mentioning this important point.

REFERENCES

Amel, D. F. and Starr-McCluer, M. Market Definition in Banking: Recent Evidence. *Antitrust Bulletin*, Spring 2002, 63-88.

Angelini, P. Are Banks Risk Averse? Intraday Timing of Operations in the Interbank Market. *Journal of Money, Credit, and Banking*, February 2000, 54-73.

Arrow, K. J. *Aspects of the Theory of Risk-Bearing*. Helsinki: Yrjö Jahnssonin Säätiö, 1965.

Attanasio, O. P. and Low, H. Estimating Euler Equations. NBER Technical Working Paper 253, May 2000.

Bankrate.com. *Bank Rate Monitor*. July 24, 1996.

Bassett, W. F. and Carlson, M. Profits and Balance Sheet Developments at U.S. Commercial Banks in 2001. *Federal Reserve Bulletin*, June 2002, 259-88.

Berger, A. N. and Hannan, T. H. The Price-Concentration Relationship in Banking. *Review of Economics and Statistics*, May 1989, 291-9.

Bernanke, B. S. and Blinder, A. S. The Federal Funds Rate and the Channels of Monetary Transmission. *American Economic Review*, September 1992, 901-21.

Campbell, J. Y. Asset Prices, Consumption, and the Business Cycle. In *Handbook of Macroeconomics* 1C, edited by J. B. Taylor and M. Woodford. Amsterdam: North-Holland, 1999, 1231-303.

Cuthbertson, K., Hall, S. G., and Taylor, M. P. *Applied Econometric Techniques*. Ann Arbor: The University of Michigan Press, 1992.

Diebold, F. X. and Sharpe, S. A. Post-Deregulation Bank-Deposit-Rate Pricing: The Multivariate Dynamics. *Journal of Business & Economic Statistics*, July 1990, 281-91.

Fama, E. F. and Gibbons, M. R. Inflation, Real Returns and Capital Investment. *Journal of Monetary Economics*, 1982, 297-323.

Feldstein, M. and Ranguelova, E. Individual Risk in an Investment-Based Social Security System. *American Economic Review*, September 2001, 1116-25.

Gilligan, T., Smirlock, M., and Marshall, W. Scale and Scope Economies in the Multi-Product Banking Firm. *Journal of Monetary Economics*, May 1984, 393-405.

Greene, W. H. *Econometric Analysis*, Second Edition. New York: Macmillan Publishing Co., 1993.

Hall, A. D., Anderson, H. M., and Granger, C. W. J. A Cointegration Analysis of Treasury Bill Yields. *Review of Economics and Statistics*, February 1992, 116-26.

Hamilton, J. D. Uncovering Financial Market Expectations of Inflation. *Journal of Political Economy*, December 1985, 1224-41.

___________. *Time Series Analysis*. Princeton: Princeton University Press, 1994.

Hannan, T. H. and Liang, J. N. Inferring Market Power from Time-Series Data. *International Journal of Industrial Organization*, June 1993, 205-18.

Hansen, L. P. and Jagannathan, R. Implications of Security Market Data for Models of Dynamic Economies. *Journal of Political Economy*, April 1991, 225-62.

Heitfield, E. A. What Do Interest Rate Data Say about the Geography of Retail Banking Markets? *Antitrust Bulletin*, Summer 1999, 333-47.

Heitfield, E. A. and Prager, R. A. The Geographic Scope of Retail Deposit Markets. Finance and Economics Discussion Series 2002-49, Board of Governors of the Federal Reserve System, August 2002.

Houpt, J. V. and Embersit, J. A. A Method for Evaluating Interest Rate Risk in U.S. Commercial Banks. *Federal Reserve Bulletin*, August 1991, 625-37.

Klein, M. A. A Theory of the Banking Firm. *Journal of Money, Credit, and Banking*, May 1971, 205-18.

Ljungqvist, L. and Sargent, T. J. *Recursive Macroeconomic Theory*. Cambridge: MIT Press, 2000.

Macaulay, F. *Some Theoretical Problems Suggested by the Movements of Interest Rates, Bond Yields, and Stock Prices in the United States Since 1856*. New York: National Bureau of Economic Research, 1938.

Mehra, R. and Prescott, E. C. The Equity Premium: A Puzzle. *Journal of Monetary Economics*, March 1985, 145-61.

Mishkin, F. S. *The Economics of Money, Banking, and Financial Markets*, Sixth Edition. New York: Addison Wesley, 2001.

Monti, M. Deposit, Credit, and Interest Rate Determination under Alternative Bank Objective Functions. In *Mathematical Methods in Investment and Finance*, edited by G. P. Szegö and K. Shell. Amsterdam: North-Holland, 1972, 431-54.

Neumark, D. and Sharpe, S. A. Market Structure and the Nature of Price Rigidity: Evidence from the Market for Consumer Deposits. *Quarterly Journal of Economics*, May 1992, 657-80.

Newey, W. K. and West, K. D. A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix. *Econometrica*, May 1987, 703-8.

Niehans, J. and Hewson, J. The Eurodollar Market and Monetary Theory. *Journal of Money, Credit, and Banking*, February 1976, 1-27.

Niehans, J. *The Theory of Money*. Baltimore: The Johns Hopkins University Press, 1978.

Radecki, L. J. The Expanding Geographic Reach of Retail Banking Markets. *Economic Policy Review*, Federal Reserve Bank of New York, June 1998, 15-34.

Ratti, R. A. Bank Attitude toward Risk, Implicit Rates of Interest, and the Behavior of an Index of Risk Aversion for Commercial Banks. *Quarterly Journal of Economics*, September 1980, 309-31.

Rhoades, S. A. Evidence on the Size of Banking Markets from Mortgage Loan Rates in Twenty Cities. Board of Governors of the Federal Reserve System, February 1992.

Rose, P. S. *Commercial Bank Management*. New York: McGraw-Hill/Irwin, 2002.

Savage, D. T. Interstate Banking Developments. *Federal Reserve Bulletin*, February 1987, 79-92.

___________. Interstate Banking: A Status Report. *Federal Reserve Bulletin*, December 1993, 1075-89.

Sierra, G. E. and Yeager, T. J. What Does the Federal Reserve's Economic Value Model Tell Us about Interest Rate Risk at U.S. Commercial Banks? *Review*, Federal Reserve Bank of St. Louis, November/December 2004, 45-60.

Stock, J. H. and Watson, M. W. Testing for Common Trends. *Journal of American Statistical Association*, December 1988, 1097-107.

___________. Business Cycle Fluctuations in US Macroeconomic Time Series, in *Handbook of Macroeconomics* 1A, edited by J. B. Taylor and M. Woodford. Amsterdam: North-Holland, 1999, 3-64.

Wright, D. M. and Houpt, J. V. An Analysis of Commercial Bank Exposure to Interest Rate Risk. *Federal Reserve Bulletin*, February 1996, 115-28.

Annex 536

C. Okereke et al., "Climate Change: Challenging Business, Transforming Politics", *Business & Society*, 2012, pp. 7-30

Business & Society
51(1) 7–30

DOI: 10.1177/0007650311427659
http://bas.sagepub.com

Climate Change: Challenging Business, Transforming Politics

Chukwumerije Okereke[1], Bettina Wittneben[2], and Frances Bowen[3]

Abstract

Climate change challenges contemporary management practices and ways of organizing. While aspects of this challenge have been long recognized, many pertinent dimensions are less effectively articulated. Based on contemporary literature and insights from articles submitted to this special issue, the guest editors of this special issue highlight some of the challenges posed by climate change to government and business, and indicate the range of options and approaches being adopted to address these challenges.

Keywords

climate change, corporate strategy, politics

In May 2011, the International Energy Agency (IEA) announced that global carbon dioxide (CO_2) emissions from energy use in 2010 reached its highest in history. At 30.2 Giga tons (Gt), energy-related CO_2 emissions rose by 5% from the previous record year in 2008 when emissions reached 29.3 Gt. Moreover, the IEA estimated that 80% of projected emissions from the power

[1]University of Reading, Berkshire, UK
[2]University of Oxford, Oxford, UK
[3]Queen Mary University of London, London, UK

Corresponding Author:
Chukwumerije Okereke, University of Reading, Department of Geography and Environmental Science, Whiteknights, P. O. Box 227, Reading, RG6 6AB, UK
Email: C.Okereke@reading.ac.uk

sector in 2020 are already locked in, as they will come from power plants that are currently in place or under construction today (International Energy Agency [IEA], 2010).

The notion that climate change poses a difficult challenge for humanity has long been recognized. The first World Climate Conference took place in 1979 and the Intergovernmental Panel on Climate Change (IPCC), an international scientific body to investigate the extent and possible impact of climate change, was established in 1988. The first IPCC report called for a global treaty on climate change, which led to the signing of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. The industrial country signatories have committed themselves to “the aim of returning individually or jointly to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases” (UNFCCC, Article 4, Paragraph 2b). The treaty went into effect in March 1994 and currently has 194 signatories.

The World Business Council for Sustainable Development (WBCSD) in its submission to the Earth Summit in Rio de Janeiro back in 1992 highlighted the difficult and almost paradoxical relationship between business and climate change: industrial activity (mostly driven by business) is the main cause for anthropogenic CO_2 emissions, so addressing climate change requires radical adjustment in industrial structure and activity. At the same time, economic development is needed to bolster innovation, clean technology, green investment, adaptation, and ultimately to achieve climate protection. The WBCSD recommendation was for a change in course for businesses and a shift away from the often adversarial relationship between business and government on environmental issues toward a more collaborative approach (Schmidheiny, 1992).

The main message of the figures released by the IEA this year is that global CO_2 emissions are almost certain to exceed the 32Gt limit for 2020 set by the most recent IPCC report (Solomon et al., 2007). Given that the global economy will most likely grow over the next 10 years with resultant increase in carbon emissions, there is a real sense that the window is closing on the opportunity to keep the average global temperature rise below 2°C as stipulated in the Copenhagen Accord and Cancun Agreements of the UNFCCC. In other words, nearly 20 years after the global agreement to fight climate change was established, the problem is still proving an extremely challenging task for governments and industry.

Given the international community’s long-standing awareness of the transformative implications of climate change for governments and business, one would have expected the scholarly field of business management to be centrally engaged with analysing the implications for business and ways of organizing.

Curiously, though, such engagement has not been the case. It was not until recently that climate change began to filter into mainstream academic management scholarship. As Amanda Goodall shows, some of the premier publications in management including the *Academy of Management Journal* and *Academy of Management Review* "did not have any article mentioning climate change or global warming (in title abstract or key word) from 1970 to 2006" (Goodall, 2008, p. 3). Furthermore, out of a total number of 31,000 published articles in the top 30 management journals over that period, "there are just nine articles that refer to climate change or global warming" (Goodall, 2008, p. 3).

In an attempt to address this oversight, guest editors Bettina Wittneben and Chuks Okereke in cooperation with Bobby Banerjee organized the very first subtheme on climate change at the 24th Colloquium of the European Group of Organizational Studies (EGOS) in 2008, which was held under the broad theme "Upsetting Organizations." They chose the subtheme title *Climate change: challenging business and transforming politics*, and invited scholars from organization studies and related disciplines to reflect on the various ways in which climate change was challenging contemporary management practices and ways of organizing. The 2008 EGOS subtheme, which the organizers extended in 2009, attracted sufficient scholarly interest and insightful contributions to encourage two of us to produce this special issue on the topic, with the support of Frances Bowen (who was a visiting fellow at the Smith School of Enterprise and Environment at the University of Oxford at the time).

It is good to see that since putting together the first EGOS subtheme on climate change, the topic of organizational response to climate change has become a recurring theme in major management scholars' conferences and publications. It is particularly notable that the Academy of Management devoted its 2010 conference to the concept of green management and that the *Harvard Business Review* had in 2007 put together a special issue on climate change. Indeed, since our initial special issue call, *Business & Society* has published several contributions addressing particular dimensions of the business implications of climate change (see, for example, Busch & Hoffmann, 2011; Linnenluecke & Griffiths, 2010; Nordberg, 2010). All of these studies indicate that, at long last, management scholars and research outlets are beginning to wake up to the enormous practical and academic significance of climate change.

In terms of process, the guest editors received 24 papers in response to our call and, based on double-blind reviewer reports, selected 10 articles to undergo revision and a second round of review. Of the 10 articles that were revised, resubmitted, and reviewed, we picked six for this special issue. The six selected articles all highlight different aspects and types of challenges posed by climate change to government and business. They also indicate the range of options and approaches being adopted to address these challenges. In this introduction, the guest editors set out the broad research questions we posed in our special issue call, and the insights on these questions collated from the articles in this issue. We focus on the challenges of climate change to business and government, and how we believe scholars of strategic management and cognate disciplines such international business, organization theory, international relations, and political economy could help address them.

Why This Special Issue?

Global climate change has become one of the most pressing issues for industry, government, and civil society in the 21st century. However, articulating the enabling institutional and political processes and the specific conditions required to achieve a response has not proved very easy. For example, while the German government, mostly in response to the recent nuclear disaster in Fukushima, Japan, has announced plans to shut down all nuclear power plants by 2022, the former Chief Scientific adviser to the UK Government, Sir David King and his colleagues are strongly encouraging the UK government to build more nuclear plants suggesting that recycling of nuclear waste is a massive economic opportunity that could be worth US$20 billion (Butler et al., 2011). The contradictory perspectives on the role of nuclear energy in climate mitigation and low carbon economy mirror the disagreements in policy discussions and business activity on investment in clean technology, renewable energy, electric vehicles, low carbon housing, green investment banks, and carbon capture and storage (cf. Brown & Chandler, 2008; Shackley, McLachlan, & Gough, 2005).

Literature on the impact of climate change on business and the range of actions taken by industry in response has been on the increase. However, many of these studies have not been very precise in the attempts to capture the dynamic interactions between governments and businesses and the organizational processes by which states and corporations develop strategies to achieve the massive cuts to greenhouse gas emissions called for by scientists.

Increasing awareness of the greenhouse gas emissions implicated in economic activities and the impact of climate change on society have led to growing calls that business has both moral and commercial obligations to take the lead in the effort to combat climate change. The conventional rationale is that harnessing the financial, technological, and organizational resources of business is vital for society to develop effective responses to climate change.

In some quarters, there are demands that governments must do more to regulate industries and corporations to promote deep reductions in emissions and foster rapid changes in business practices and culture (Nordberg, 2010). However, amidst this growing call for a change in philosophy, business is being looked on to finance economic growth and meet the rising demand for consumer goods and services worldwide. The pressure to achieve deep emission reductions and economic growth simultaneously poses challenges to business and government, particularly in the context of the current economic crisis and the ever-increasing domestic and global economic competition.

At the same time, the last three decades or so have witnessed profound transformations in the global political economy landscape with deep interconnections between the political and the economic domains.These shifts have blurred the traditional divide between the private and the public as exemplified by the proliferation of unique public and private partnerships (PPP). Thus, it is now somewhat difficult to determine what and how much can be demanded from business actors, who would be best placed to demand such changes, and where exactly the levers for society-wide transformations reside.

Given these trends, and the relative paucity of management research on the interface between climate change, business and government, the guest editors posed three key research questions in our special issue call:

Research Question 1: What are the institutional and organizational challenges posed by climate change to business and government, and to what extent are these challenges transforming relations within and between these entities?

Research Question 2: How do firms seek to navigate, influence, dominate, or transform political processes addressing climate change and what effects does this activity have on the approaches by which states and corporations develop strategies for climate change?

Research Question 3: What insights might be drawn for effective climate mitigation and adaptation actions from understanding the inter actions between corporate actors, policy makers, and civil society?

Our objective in this special issue was to bring together insights from strategic management, organization theory, international relations, and political economy to better understand how climate change is challenging and transforming traditional business models and political approaches. Since firms do not act in isolation, but rather in concert with or as part of public policy and civil society, scholars need to understand business carbon strategy as part of the broad field of climate change policy. This need calls for an exploration of agency and levers for achieving the much-needed transition to low-carbon business models necessary to avert dangerous climate change. The guest editors encouraged contributors to reflect on the roles of individual corporate leaders, organizational culture, competitively valuable capabilities, alternate organizational forms, and sociopolitical regimes in shaping corporate strategies to address climate change.

In the next three sections, the guest editors draw insight from articles in this issue and our own reading of the contemporary climate strategy and politics literatures to answer the three research questions above. We begin by discussing the organizational and institutional challenges posed by climate change, pointing to the impact on organizational capabilities, culture, structure, and processes. We go on to analyze the business responses to climate change outlined in this issue, and derive an integrative framework for categorizing corporate climate change strategies. Finally, we synthesize the recommendations found in this special issue to bring about a transition to a low carbon economy and use them to generate fruitful avenues for future research.

Organizational and Institutional Challenges of Climate Change

Climate change has been variously framed as an environmental threat (Gore, 2006), a market failure (Stern, 2006), a moral dilemma (Hulme, 2009), and a sociopolitical challenge (Giddens, 2009). Climate change is in some sense all of these things, but as Evans and Steven (2009, p. 2) aptly point out, the "challenge is above all one of leadership, coordination and collective action—and hence about institutions." Since institutions embody a complex web of beliefs, norms, rules, and structure, it is fair to surmise that innovation, changes, and coordination at all of these levels is required to achieve effective response to the challenge. This is an enormous task which is complicated by the uncertainty implicated in the science of climate change, the large number of actors required to deal with the problem (see Pinkse & Kolk, in this issue), and the fact that effective institutions are rarely just designed but tend to evolve organically especially in response to shocks and changes in their external environment (North, 2006; cf. Haigh & Griffiths, in this issue).

Institutions mediate between organizations, society, and the natural environment. Climate change upsets established institutional arrangements through physical and political adjustments and shocks. These challenges affect organizations in different ways. Impacts are dependent on a number of factors such as size, location, and industry-type (Okereke, 2007) and affect organizations

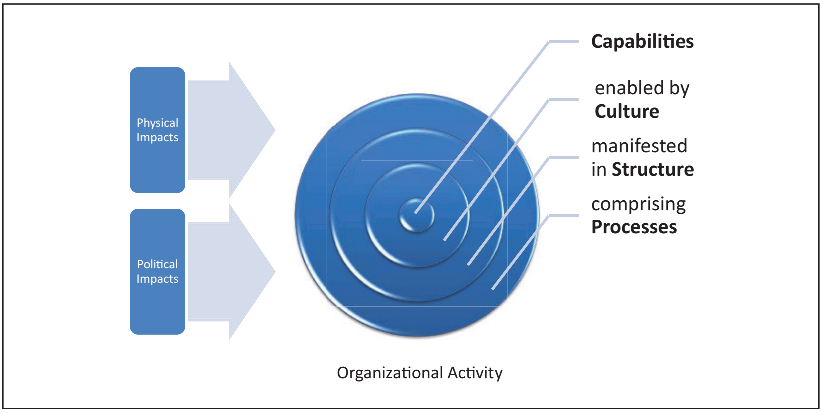


Figure 1. Climate Change Impacts on the Organization

on various levels. As an analytical tool, the guest editors developed four strata that are affected by climate change issues. These strata include organizational *capabilities*, *culture*, *structure*, and *processes*. Contributors to this special issue all highlight different aspects of these challenges. Figure 1 displays the relationships among the strata, Table 1 presents examples.

The first, and arguably the most important organizational challenge posed by climate change is the demand for new *capabilities* throughout the organization (Furrer et al.; Haigh & Griffiths; Rothenberg & Levy; and Thistlethwaite, in this issue). To assess the risks and opportunities associated with climate change and evaluate response options, an organization must necessarily possess or otherwise engage those that have requisite capabilities. Similarly, specific capabilities are required to formulate and implement strategy; and to engage employees and external relations. The capabilities challenge of climate change is particularly formidable because in addition to the high level of uncertainty mentioned, the phenomenon embodies complex technical and multifaceted dimensions ranging from physical science through management to ethics and philosophy (Kelly & Kolstad, 1999; cf. Pinkse & Kolk, in this issue).

Thistlewaite (in this issue), for example, shows that a major obstacle faced by the insurance industry in their attempt to respond to climate change relates to skills and capability difficulties in constructing risk models that incorporate climate change. To evaluate the risk and develop products, he argues, an insurance company must be able to "model or quantify the chances of a weather-related event occurring and the losses associated with this event." This need means that insurance companies have to use modeling

Table 1. Organizational Challenges of Climate Change

	Capabilities	Culture	Structure	Process
Examples	Climate science Leadership Climate managers Climate public relations expert Carbon measurement and accounting	Printing rate and format Switching off lights Waste recycling Travel mode and frequency Telephone and video conferences	Relocation of headquarters Change or relocation of infrastructure Change in complexity and scale Change in operational model Change in decision making model	New technology New production process New raw material New supply chain

techniques that incorporate future climate change conditions into their premium pricing. The problem, however, is that the prevailing practice in the industry is based on actuarial analysis that models future risks based on the magnitude and frequency of past events. Because the models the industry uses to manage and price risk have been backward looking (based purely on historic data) they are incapable of dealing with the future-oriented uncertainty and increasing weather-related losses. Thistlewaite goes on to note that major insurance companies have responded by developing near-term models that can be used to inform exposure to short-terms risks on an annual basis, but reports that "models that inform rates based on longer term risks associated with climate change represent a significant technical challenge."

Moreover, the challenge is not simply that of the acquisition of the right set of skills and capabilities (Furrer et al., in this issue), it is also about distilling "truths" and insights for effective strategy from the often competing voices within the corporation or government. Rothenberg and Levy (in this issue) make this point well in their contribution on the role of corporate environmental scientists in shaping corporate perceptions about, and responses to climate change. Through their involvements as "filters," "institutional interpreters," "translators," or the "clearing house for information" on climate change, in-house scientists can often serve as effective "boundary spanners" helping to frame corporate response and strategy. At the same time, they show that the perception and use of science by corporations is a messy and complex process shaped by several factors bordering on organizational structure, history, and culture. Critically, while senior executives attempt to work out a defined strategy and "speak with a single authoritative voice in public," there are frequently significant internal tensions resulting from differences in level of knowledge, risk exposure, training, background, operational focus, and personal beliefs of managers (see also Haigh & Griffiths, in this issue). Hence the process of organizational sensemaking involves sifting through and balancing these competing opinions, coalitions, and discourses within a firm. This process can present a formidable challenge to companies seeking to design effective response to climate change (Haigh & Griffiths, in this issue).

Consider another example: corporate accountability for carbon emissions, which is increasingly being recognized as vital in combating climate change (Williams & Crawford, in this issue). In 2010, 534 institutional investors representing more than US$64 trillion of assets under management threw their weight behind the eighth Carbon Disclosure Project (CDP) demanding corporate primary climate change data from more than 4,700 of the world's largest corporations. In response, 82% of Global 500 companies voluntarily reported their carbon emissions, which in total amounts to about 3.4 billion metric tons CO_2-e, and represents about 11% of total global emissions.

However, with an increasing level of scrutiny and demand for publicly availability climate information, mainstreaming corporate carbon accounting and increasing quality and rigor present a number of skills and capability challenges. First, carbon accounting relies on company's ability to measure and report physical carbon dioxide emissions. This is not as straightforward as it may seem since the science of carbon emissions measurement is still developing with a large number of different measurement protocols, emissions factors, estimations, and calculations used. Second, because the most accurate carbon measurement techniques may also be the most expensive to implement, companies may face the choice between increasing accounting accuracy and saving cost. Third, within the overall aim of achieving emission reduction, different decision contexts may require that different measurement features be prioritized. Therefore, to ensure accurate and "fit for purpose" accounting, managers need to decide when to prioritize consistency over accuracy (Bowen & Wittneben, 2011).

In addition to the physical measurement of greenhouse gas molecules, effective carbon accountability requires that corporations develop skills on how to crunch these numbers and integrate them into the balance sheet and other financial statements of the company in a consistent and generally accepted format. Again, this task is not easy as accounting for costs related to natural resources, including water and waste, has always presented unique challenges to traditional methods for corporate financial accounting (Lamberton, 2005). Moreover, since the process of measurement of emissions, disclosure, and target setting is in most cases the outcome of pressure from stakeholder groups and activists (Williams & Crawford, in this issue) managing external relations can also be an important aspect of corporate climate strategy.

Other skills challenges identified by contributors to this volume include the ability to forecast impact, the ability to manage trading exposure effectively (Haigh & Griffiths, in this issue); communication skills, ability to analyze risk profiles for new green technologies, and team management. In fact, after observing the range of capability requirement for banks wishing to engage seriously with climate change, Furrer et al. (in this issue) declare that developing adequate climate response by any company is "likely to change the capability portfolio" of such an organization.

The second broad category of organizational challenge of climate change has to do with the imperative for value and culture shift. Effective response to climate change does not simply require the installation of new and glitzy technologies like smart meters or solar panels; it also demands, in most cases, a lot of basic or fundamental changes in behavior. But organizational cultures are often deeply entrenched and hard to change. Moreover, communicating to achieve climate change behavior change can be particularly difficult for many reasons including controversy in science, improbability between cause and effect, and a sense that individual single effort will not make much of a difference to the overall outcome.

Hence, even though many changes are often described as ‘‘low hanging fruit’’ in that they are relatively easy to implement and often lead to reduction in energy consumption (Hoffman, 2006, p. 16); one finds that getting employees to adopt these new modes of behavior can sometimes prove extremely difficult. Whether one is interested in getting employees to reduce printing rate, print double-sided, recycle waste, switch off lights, substitute travel with video conferencing, or embrace a new low carbon business model, research shows there are often serious value and culture-related factors that can easily impede sources.

Critically, the culture shifts required for combating climate are not always as straightforward as remembering to flick off a power switch or even achievable without the cooperation of a broad spectrum of relevant actors. A number of company workers may have the desire to recycle waste, but achieving this objective may require a set of logistical support and organizational arrangements beyond the remit of the green-minded group of workers. Haigh and Griffiths (in this issue) discuss this challenge in relation to an electricity distributing company that needed to cope with increasing ambient temperatures, heat wave, and rising demand in product. This distributor, as they report it,

> became involved in a federal demand management initiative to build management capabilities which had significant cultural implications for the company, because “it is quite non-traditional for the business to think about spending money that way rather than building more poles and wires . . .”

In other words, the company not only had to undergo internal cultural transformation, it needed to secure such a shift in the broader community to ensure the success of their carbon management strategy. This condition is similar to the point made by Rothenberg and Levy (in this issue) that an automobile company may be willing to invest in making electric or smaller more fuel efficient cars, but would require a societal-wide change in culture and willingness to embrace smaller cars to justify such investment.

In addition to, and sometimes because of the skills and culture-based requirements for corporate carbon management, important structural challenges may also arise. These challenges may include the need to restructure to create new teams, units, or lines of responsibility. In other instances, there may be the need to relocate physically offices and infrastructure or to change the organizational or operational model to keep pace with new portfolio or technology. Furthermore, carbon management could also result in changes in the complexity and scale of organizations, changes in decision-making models, or changes in the operational model of aspiring corporations.

A clear example of such fundamental organizational restructuring due to climate change is provided by Haigh and Griffiths (in this issue). They found that after several rounds of paying another plant to generate base load electricity at unusually hot summers to meet its federal mandate, a major electricity transmitting company in Australia had to divide its region into five subregions to “attempt to forecast temperature and demand at a more granular level.” Thistlewaite (in this issue) finds that in response to series of unprecedented severe weather events and huge losses in early 2000, many insurance companies in the United States pulled back from already established markets, with some closing down or significantly rejigging their operational structure as a result. Furrer et al. (in this issue) go further by suggesting that there is a strong and direct correlation between change in the management framework of business and their strategy as well as “their understanding of what constitutes appropriate action.”

In the early 2000s, and under heavy pressure from the public and governments, some major oil companies including Shell and British Petroleum (BP) made significant investments in renewable energy especially wind and solar. However, by 2008 the oil majors divested from most of these projects claiming among other reasons that the investments caused undue stretch on their traditional competences and operational processes. The oil industries were of course heavily criticized for moving away from renewable (Backer & Clark, 2008; Levy, 2009) but it is hard not to be sympathetic with the point made regarding the structural and procedural challenges involved in moving from the extraction and sale of oil to the installation and running of wind and solar farms (see Pinkse & van den Buuse, 2012). Even for a traditional power or utility company, switching from electricity generation through coal or nuclear to say gas or wind cannot be regarded as an easy, unproblematic prospect (cf. Wittneben & Kiyar, 2009).

The fourth and last broad organizational challenge of climate change relates to process. The design and implementation of carbon reduction plans or more ambitiously the integration of carbon management into the strategic priority of business in most cases would require important process-based changes for aspiring organizations. These can be straightforward changes covering new additional measurements, reporting or information provision or more far-reaching and complex adjustments involving changes in production processes based on new technology, alteration of raw materials, and even changes in products. Where carbon response strategy involves changes in production process and products, additional changes in advertising, and marketing strategy and customer relations may yet be required.

Furrer et al. (in this issue) make this argument with regard to the banking industry. They suggest that it is practically impossible for any bank to achieve serious engagement with climate change without far-reaching changes in everyday business processes and practice. In fact, their typology of climate strategy in the banking industry differentiates offsetting and mitigation, which they argue to be mostly symbolic activity warranting no change on process and substantive activities such as equity research, financing, due diligence, advisory services, monitoring, and the development of new investment portfolio, which they argue could not be achieved without radical process-based changes.

The above four broad organizational challenges of climate change have been discussed mainly with focus on business and industry reflecting the bias of the articles received for the special issue; but the points made are equally applicable, if not more so for governments. Pinkse and Kolk (in this issue) are spot on when they observe that one of the main justifications for multistakeholder partnerships for climate change is that they provide platform that help "to effectively cross-leverage resources, knowledge and expertise," which otherwise reside in different sectors. At the same time, since governments are often larger, more complex, and in many ways differently organized than corporations, the difficulties they face in relation to achieving cultural, structure, and process changes relevant for combating climate change can be far more formidable.

The next section turns to the question on business strategies that address climate change.

Business Strategies for Climate Action and Political Leverage

The second research question the guest editors posed in the call for papers asked contributors to focus on firms' responses to the climate change challenge: "How do they navigate, influence, dominate, or transform political processes addressing climate change?" Early research efforts classified firms' corporate climate strategies along a continuum or typology ranging from offensive, reactionary through passive to proactive, analogous to the broader corporate political strategy literature: see, for example, Levy and Kolk's (2002) application of Gladwin and Walter's (1980) framework. These typologies were useful in understanding the broad political positions of key multinational companies on climate policy but they did not provide much information regarding the internal strategies adopted by the companies.

Others have promoted more internally focused strategy "classifications such as product versus process oriented, internal versus external, direct versus indirect, radical versus incremental, and innovation versus compensation" (Okereke, 2007, p. 478; cf. Kolk & Pinkse, 2004, 2005). A frequently cited typology developed by Kolk and Pinkse (2005), for example, suggests that companies differ on two important aspects with respect to their climate strategy. The first is strategic intent. This aspect refers to the degree to which a company's carbon management is focused on innovation through production process and product development as opposed to compensating for its climate impact; say through offset and carbon trading. The second aspect is the form of organization adopted by a company. This aspect refers to the distribution of focus between internal processes, supply chain, or cooperation with other companies. In another example, Hoffman (2006) differentiates corporate internal carbon strategy on the basis of a continuum, from assessing emission profiles to evaluating options to formulating policy strategy.

These new sets of typologies represented significant improvements to the earlier politically oriented schemas. However, they remained weak in providing empirical evidence and examples of specific activities to support these taxonomies and in explaining what drives organizations to take a particular approach. Furthermore they have been criticized for "considering the broader political institutional environment as exogenous mediators and focusing on 'pure' market factors in a bid to explain strategy" (Okereke & Russel, 2010, p. 103). The guest editors encouraged our special issue contributors to both flesh out the details of firms' actions on climate change and to make the connections between climate strategies and transforming the political context.

Based on the contributions to this special issue, we can see two key dimensions of firms' climate strategies that have so far been relatively neglected in the literature. First, researchers usually focus on how businesses act to address the causes of climate change (i.e., reducing greenhouse gas emissions). Previous literature has tended to focus on mitigation actions and failed to give sufficient attention to companies' adaptation strategies. In contrast, the articles by Haigh and Griffiths and by Pinkse and Kolk in this special issue are valuable contributions to our understanding of business' responses to the consequences of climate change. Haigh and Griffiths provide an inductive analysis of the electricity supply industry in Australia, showing how climactic surprises lead businesses to adapt their operations and strategy to the consequences of climate change. Pinkse and Kolk argue that climate change adaptation is particularly important in the developing country context, given that they are "hit much harder by physical impacts than industrialized countries, the low level of development and lack of funds." Dealing with the consequences of climate change requires different governance arrangements from mitigating its causes. These articles signal the distinctive strategies needed to address climate change mitigation and adaptation (Wittneben & Kiyar, 2009).

A second dimension of corporate climate strategy that emerged from these articles is the system that the corporate activities are intended to influence. Submissions to our special issue demonstrated a fundamental difference between strategies targeted at business' interactions with biophysical systems (e.g., limiting emissions; modeling climactic changes), and those addressing interactions with politico-economic systems (e.g., changing stakeholder demands, markets, and regulations). Several submissions highlighted how these strategies have become decoupled, with climate change "action" by firms largely focused on signaling within the politico-economic system rather than influencing physical climate change. Pinkse and Kolk's analysis in the sustainable development context, for example, shows the predominance of policy formulation over policy implementation governance. Multistakeholder partnerships directed at policy formulation can satisfy risk management demands in the politico-economic system, but without having any impact whatsoever on biophysical climate change.

Figure 2 builds on these two dimensions to provide an integrative typology of corporate climate strategies. The vertical axis shows that firms seek to navigate, influence, dominate, or transform either biophysical or politico-economic

Strategy system focus	Climate change causes	Climate change consequences
Biophysical system	**1. Biophysical mitigation** Reduce amount of GHGs emitted	**3. Biophysical adaptation** Change practices due to new climactic conditions
Politico-economic system	**2. Politico-economic mitigation** Manage socio-economic risks from GHG emissions	**4. Politico-economic adaptation** Change practices due to new socio-economic conditions
	Business challenge origin	

Figure 2. An Integrative Typology of Corporate Climate Strategies

processes. The horizontal axis captures whether the firms' actions address challenges arising from the causes or the consequences of climate change. Our contributors do provide examples of strategies to reduce the amount of greenhouse gases, particularly carbon dioxide that is released into the biophysical environment. Such biophysical mitigation strategies (cell 1 in Figure 2) include process changes like energy efficiency measures in banks (Furrer et al., in this issue), product launches like GM's Volt launched in December 2010 (Rothenberg & Levy, in this issue), and multistakeholder partnerships such as Energy Poverty Action and the Partnership on Sustainable Low Carbon Transport (Pinkse & Kolk, in this issue). Corporate biophysical mitigation strategies are vital to slow the progress of climate change; and yet most of the articles received showed scant evidence of genuine strategies of this type designed to aggressively reduce the amount of greenhouse gases emitted. Furrer et al. pointed out that biophysical mitigation strategies in banks are of such minor importance compared with changing lending practices that they could be classified as "symbolic" climate strategies. And Rothenberg and

Levy outline in detail the painful cultural process at GM over 20 years that eventually led to authentic biophysical mitigation activities.

Instead, our contributors focused on corporate activities directed at the politico-economic system. Politico-economic mitigation strategies (cell 2) are based on firms' activities to manage pressures to reduce greenhouse gas emissions within the institutional, political, economic, and social systems. Rothenberg and Levy, for example, theorize corporate environmental scientists as boundary spanners between the emerging science of the need for carbon emissions mitigation and automobile manufacturers' strategies. In another example, Williams and Crawford's article emerges from the corporate political activity (CPA) tradition, positioning corporate climate strategies as "designed to signal their policy position in an attempt to shape shareholders' and activists' views, believing that these groups may help, ultimately, shape government policy as well." Notably, both of these articles highlight how firms use intermediaries within politico-economic mitigation strategies: they focus alternatively on shareholders and activists (Williams & Crawford), and the scientific community (Rothenberg & Levy) as intermediaries between firms and policy makers.

Haigh and Griffiths argue for a shift in perspective from strategies addressing stakeholder management and the politics of carbon mitigation legislation (cell 2) toward strategies addressing biophysical adaptation (cell 3). They argue that business responses to climate change "occur predominantly as a reaction to climatic surprise, rather than a preemptive response to increasing awareness, and perceived uncertainty and risks as suggested by previous studies." They delineate how rising ambient temperatures, reduced water availability, and increased incidence and intensity of extreme weather events led to operational impacts on electricity supply organizations' activities. Climactic changes led firms to modify strategy and project development processes, and to enter new trading markets. Notably, climate surprises led electricity supply companies to be less politically oriented in their climate strategies and to change their strategic and operational practices to incorporate the new physical climate realities.

Such biophysical adaptation strategies can be seen in industries as diverse as housing construction, water provision, tourism, agriculture, and health (Berkhout, Hertin, & Gann, 2006; Hoffmann, Sprengel, Ziegler, Kolb, & Abegg, 2009; Wittneben & Kiyar, 2009). Contributions in this volume also highlight politico-economic adaptation strategies (cell 4). Insurance companies and banks do not need strategies to address direct physical threat to their operations, but as Thistlethwaite and Furrer et al. point out in their articles, they need to develop strategies to cope with the physical consequences of climate change in their clients' operations. The insurance industry's ClimateWise strategy provides an illustrative example of politico-economic adaptation: "ClimateWise emerged in response to strategic incentives and institutional conditions related to increasing weather-related losses linked with climate change within insurance markets" (Thistlethwaite, in this issue). This self-regulatory strategy is designed to develop the insurance industry's technical authority on how to model and insure climate-related risks. More importantly, it is also aimed at leveraging the industry's political authority in governing the physical risks of climate change. Lobbying strategies in cell 4 are more aimed at national and international regulations that price economic behavior exposed to the consequences of climate change, rather than preemptive carbon mitigation (cell 2).

Most of the research literature before this special issue was focused on the left-hand side of Figure 2 (i.e., cells 1 and 2). The guest editors would encourage more research on exploring the form, barriers, enablers, and contingencies of climate change adaptation (i.e., cells 3 and 4). Haigh and Griffiths and Pinkse and Kolk's articles delineates clearly the threats from the consequences of climate change. A question that is rarely asked, perhaps because it seems distasteful in the light of climate change-related mass migration, health effects, and pressures on basic needs in developing countries, is about the business and political opportunities inherent in climate change adaptation. These opportunities might range from the relatively banal, such as the extension of wine-growing regions in Italy (Jones, White, Cooper, & Storchmann, 2005), to the seriously environmentally consequential, such as opening up the Arctic for offshore oil and gas development. There are tough questions to be asked about who gains commercially and politically from climactic changes. We would encourage more research on how climate change adaptation is shifting the commercial and political landscape so that some industries, firms, and coalitions may be weakly incentivized to address the causes of climate change.

Furthermore, much of the discourse around business and climate change is stuck in the bottom half of Figure 2, asking how firms navigate the reputational, regulatory, and financial risks arising from climate change. Too little management research explicitly connects corporate climate strategies with changes in the biophysical system. There are practical problems with achieving this, of course, such as the accuracy and consistency in carbon emissions data to measure induced changes in the biophysical system (Bowen & Wittneben, 2011). The global scale of GHG emissions and climate changes also makes it impossible to attribute changes in the biophysical system to particular firms. But this reality does not absolve firms, and management researchers who comment on them, of the responsibility to evaluate the eventual ecological impacts of corporate climate strategies.

Insights for Effective Climate Mitigation and Adaptation Actions

Our third broad question related to the key insights for effective climate response based on the more than 20 years of engagement with the issue so far. This is in a sense the most difficult of the three key questions the guest editors posed in the beginning because as stated, available emission statistics and projections do not suggest that either governments or industry have done particularly well so far in decarbonizing the global economy and addressing the threat of climate change.

With respect to governments, regulations are still nonexistent in many political jurisdictions or at best patchy and incoherent. A number of political jurisdictions appear to have embraced emission trading schemes as the main framework for tackling climate change but emission trading has proven to be ineffective as a tool to lower emissions and instead comes at a much greater cost to the economy than more traditional approaches such as carbon taxes (Wittneben, 2009). Only recently in Cancun, parties to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol decided that all governments should design and implement a low carbon development plan but only few have so far started to act on this decision. Indeed, the entire global climate governance regime stands at a precarious juncture with the future of the Kyoto Protocol looking very uncertain (Rajamani, 2011).

Similarly, with respect to corporations, many are, as noted, undertaking a lot of activities ranging from emission measurement, through reporting to investments in technology. However, for ostensibly the reasons discussed in the previous sections, very few indeed have embraced actions that can be truly described as a radical departure from business as usual. Furrer et al. (in this issue) analyze 114 listed banks around the world and find that most “banks that implement a climate strategy often decouple it from their main value creating process such as lending and investment.” This finding is very much consistent with those of other scholars, which suggest that the business strategy of many corporations, for the most part, consist in shuffling, deferral, hedging, and managing new risks with currently existing approach and capabilities (Lash & Wellington, 2007; Levy & Kolk, 2002; Okereke & Russel, 2010).

Although the general public and governments have been pushing business to take action, regulations have been patchy, public engagement has been mostly shallow, and green consumerism has not been robust enough to drive innovation. Only recently, Google announced that it is pulling the plug on PowerMeter, its home online monitoring tool, because it failed to catch on with consumers and the commercial office sector does not appear to be faring much better in adopting energy monitoring. As Rothenberg and Levy (in this issue) show, neither GM nor Ford felt able to commit significant investment to low carbon automobile design "with gasoline at $1 a gallon, consumers who care little for fuel environment and are hungry for large SUVs."

That said, it is still possible to glean a few insights for effective climate action from the currently messy landscape. These preconditions for successful engagement apply equally both to governments and corporate organizations.

First and most importantly, effective climate action requires serious engagement and commitment by senior leadership from within governments and corporate organizations. Given as discussed, the multidimensional challenges of climate change and the deep institutional changes required to address these challenges; it is not conceivable that any organization or political jurisdiction can go far in articulating effective response without robust and sustained engagement of the leaders at the highest level of decision making. It is not a surprise, therefore, that the few organizations that have shown leadership in tackling climate change all have proactive senior level managers who have shown personal commitments in driving change (Furrer et al., in this issue; Wittneben, 2009).

An important dimension of leadership that emerged from the contributions to this volume is the role of individual entrepreneurs in facilitating change in both organizations and the wider society. Thistlethwaite (in this issue) highlights the roles of Tessa Tennant and Paul Dickenson, two entrepreneurs working in the UK investment industry in the formation of the now globally important CDP. Furthermore, he argues that the Prince of Wales of the United Kingdom and a few executives in the insurance industry played important roles as institutional entrepreneurs in the development of the ClimateWise Principles. Similarly, Rothenberg and Levy (in this issue) suggests that the leadership shown by GM in the early stages of the automobile industry's engagement with climate change owes a lot to the activities of corporate scientist Ruth Reck.

Second, effective climate mitigation and adaptation requires the availability of the right mix of technical and institutional capacity (see Haigh & Griffiths; Rothenberg & Levy; and Thistlethwaite, in this issue). Governments and corporations alike need to make informed choices about how their middle and long-term operations may be affected by climate change and the best response options. However, effective design and implementation of strategy requires a menu of high-level skills and expertise. Relying on old and preexisting set of skills and capabilities to handle the new risks and challenges posed by climate change is bound to lead to suboptimal and ineffective response strategy. Although there are notable exceptions, Furrer et al. (in this issue) demonstrate a strong link between substantive climate action of banks with size and the "the capacity to develop the complex resources to implement a systematic and comprehensive strategy."

The third precondition for successful climate action is proper and consistent engagement and communication with relevant stakeholders—both within and outside the confines of the organization. Effective communication is absolutely essential for the purpose of mobilization; achieving buy-in and agreeing consensus over priorities (see Thistlethwaite and Williams & Crawford, in this issue). This communication is necessary especially because to a greater or lesser degree all climate change response measures involve trade-offs along with their benefits. Hence, a measure of consensus and synergy is required across board; from the board room to the boiler room; and from the federal governments to municipal councils. Although as Pinkse and Kolk (in this issue) show, bringing sectors with different perspectives together can cause some discomfort, such integration is nonetheless absolutely necessary for international education, reducing company level dissonance, and crafting coherent and robust strategy (cf. Rothenberg and Levy, in this issue).

Fourth, there must be willingness by both organizations and governments to abandon old ways of and try new methods for doing things. It is important to recognize that there are no templates for dealing with challenge of climate change. The present generation constitutes quite simply the pioneers, which requires a willingness to learn by doing.

Last, governments and corporations must show greater determination to put their money where their mouths are. There is simply no running away from the fact that addressing climate change will cost money. However, since there is equally a great (or perhaps greater) cost in not taking action, committing the right amount of financial resources toward innovation, research and development, clean technology, capacity building, and achieving value reorientation looks ultimately a wise decision.

Conclusions

Climate change poses new and unprecedented challenges to business and politics. This introduction has highlighted some key aspects of these challenges. While there have been serious activities by many relevant actors—corporations and governments alike—it does appear that most of these are not transformational enough to reverse climate change (cf. Whiteman, Dorsey, & Wittneben, 2010). This special issue attempts to bring together insights from some of the leading scholars in the field to examine the challenges associated with climate change and understand effective responses by both government and industry.

Acknowledgments

The authors would like to thank Duane Windsor, the editor of *Business & Society*, for supporting this theme for a special issue for this journal and the logistical support he gave us in the production process.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The authors would like to acknowledge the Smith School of Enterprise and Environment at the University of Oxford for financial support provided through the academic visitors program. Administrative support was partly funded by IRIS (International Resource Industries and Sustainability Centre) at the University of Calgary (SSHRC Grant No. 603-2007-0010).

References

Backer, L., & Clark, T. S. (2008). Eco-effective greening decisions and rationalizations: The case of Shell renewable. *Organization and the Environment, 21*, 227-244.

Berkhout, F., Hertin, J., & Gann, D. M. (2006). Learning to adapt: Organisational adaptation to climate change impacts. *Climatic Change, 78*, 135-156.

Bowen, F. E., & Wittneben, B. (2011). Carbon accounting: Negotiating accuracy, consistency and certainty across organizational fields. *Accounting, Auditing and Accountability Journal, 24*(8), 1022-1036.

Brown, M. A., & Chandler, S. J. (2008). Governing confusion: How statutes, fiscal policy, and regulations impede clean energy technologies. *Stanford Law & Policy Review, 19*, 472-509.

Busch, T., & Hoffmann, V. H. (2011). How hot is your bottom line? Linking carbon and financial performance. *Business & Society, 50*, 233-265.

Butler, G., McGlynn, G., Evans, M., Ion, S., Owens, O., & King, D. (2011). *A low carbon nuclear future: Economic assessment of nuclear materials and spent nuclear fuel management in the UK*. doi:10.4210/ssee.pbs.2011.000; ISSN: 2042-4043. Retrieved from http://www.smithschool.ox.ac.uk/nuclearreport2011/nuclear_study_sm.pdf

Cembureau. (2006). *Key facts: Cement industry contributes to waste management*. Brussels, Belgium: Author. Retrieved from http://www.cembureau.be/

Evans, A., & Steven, D. (2009). *An institutional architecture for climate change: A conceptual paper*. Commissioned by the Department for International Development, United Kingdom.

Furrer, B., Hamprecht, J., & Hoffmann, V. H. (in this issue). Much ado about nothing? How banks respond to climate change. *Business & Society*.

Gladwin, T. N., & Walter, I. (1980). How multinationals can manage social and political forces. *Journal of Business Strategy, 1*(1), 54-68.

Giddens, A. (2009). *The politics of climate change*. Oxford, UK: Polity.

Goodall, A. (2008). Why have leading journals in management (and other social sciences) failed to respond to climate change? *Journal of Management Inquiry, 17*(4): 408-420.

Gore, A. (2006). *An inconvenient truth: The planetary emergency of global warming and what we can do about it*. Emmaus, PA: Rodale Books.

Haigh, N., & Griffiths. A. (in this issue). Surprise as a catalyst for including climatic change in the strategic environment. *Business & Society*.

Hoffman, A. J. (2006). *Getting ahead of the curve: Corporate strategies that address climate change*. Arlington, VA.: Pew Center on Global Climate Change.

Hoffmann, V. H., Sprengel, D. C., Ziegler, A., Kolb, M., & Abegg, B. (2009). Determinants of corporate adaptation to climate change in winter tourism: An econometric analysis. *Global Environmental Change, 19*, 256-264.

Hulme, M. (2009). *Why we disagree about climate change: Understanding controversy, inaction and opportunity*. Cambridge, UK: Cambridge University Press.

International Energy Agency. (2010). *The IEA's 2010 world energy outlook*. Retrieved from www.worldenergyoutlook.org

Jones, V. G., White, A. M., Cooper, R. O., & Storchmann, K. (2005). Climate change and global wine quality. *Climatic Change, 73*, 319-343.

Kelly, D. L., & Kolstad, C. D. (1999). Integrated assessment model for climate change. In F. Holmer & T. Tietenberg (Eds.), *International year book for environmental and resource economics 1999/2000: A survey of current issues* (pp. 171-197). Cheltenham, UK: Edward Elgar.

Kolk, A., & Pinkse, J. (2004). Market strategies for climate change. *European Management Journal, 22*, 304-314.

Kolk, A., & Pinkse, J. (2005). Business response to climate change: Identifying emergent strategies. *California Management Review, 47*(3), 6-20.

Lamberton, G. (2005). Sustainability accounting—a brief history and conceptual framework. *Accounting Forum, 29*, 7-26.

Lash, J., & Wellington, F. (2007). Competitive advantage on a warming plant. *Harvard Business Review, 85*(3), 94-102.

Levy, D. L. (2009, August, 13). Back to petroleum. *Climate Inc*. Retrieved from http://climateinc.org/2009/08/back-to-petroleum/

Levy, D. L., & Kolk, A. (2002). Strategic responses to global climate change: Conflicting pressures on multinationals in the oil industry. *Business and Politics, 4*, 275-300.

Linnenluecke, M., & Griffiths, A. (2010). Beyond adaptation: Resilience for business in light of climate change and weather extremes. *Business & Society, 49*, 477-511.

Nordberg, D. (2010). Review essay: Disagreeing about the climate. *Business & Society, 49*, 549-557.

Okereke, C. (2007). An exploration of motivations, drivers and barriers to carbon management: The UK FTSE 100. *European Management Journal, 25*, 475-486.

Okereke, C., &, Russel, D. (2010). Competitive dynamics and regulatory pressure: Impacts on the carbon management strategies of UK energy intensive companies. *California Management Review, 52*(4), 100-124.

Pinkse, J., & Kolk, A. (in this issue). Addressing the climate change—sustainable sevelopment nexus: The role of multistakeholder partnerships. *Business & Society*.

Pinkse, J., & van den Buuse, D. (2012). The development and commercialization of solar PV technology in the oil industry. *Energy Policy, 40*, 11-20. doi: 10.1016/j.enpol.2010.09.029

Rajamani, L. (2011). The Cancun climate change agreements: Reading the text, subtext and tealeaves. *International & Comparative Law Quarterly, 60*, 499-519.

Rothenberg, S., & Levy, D. L. (in this issue). Corporate perceptions of climate science: The role of corporate environmental scientists. *Business & Society*.

Rowlands, I. H. (2000). Beauty and the beast? BP's and Exxon's positions on global climate change. *Environment and Planning C: Government and Policy, 18*, 339-354.

Schmidheiny, S. (1992). *Changing course: A global business perspective on development and the environment*. Cambridge, MA: MIT Press.

Shackley, S., McLachlan, C., & Gough, C. (2005). The public perception of carbon dioxide capture and storage in the UK: Results from focus groups and a survey. *Climate Policy, 4*, 377-398.

Stern, N. (2006). What is the economics of climate change? *World Economics, 7*(2), 1-10.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., & Miller, H. L. (Eds.). (2007). *Climate Change 2007: The physical science basis* (Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change). Cambridge, UK: Cambridge University Press. Retrieved from http://ipcc-wg1.ucar.edu/wg1/wg1-report.html

Thistlethwaite, J. (in this issue). The climate wise principles: Self-regulating climate change risks in the insurance sector. *Business & Society*.

Whiteman, G., Dorsey, M., & Wittneben, B. (2010, July 22). Business and biodiversity: They would say that. *Nature, 466*, 435.

Williams, C. C., & Crawford, E. P. (in this issue). Influencing climate change policy: The effect of shareholder pressure and firm environmental performance. *Business & Society*.

Wittneben, B. (2009). Exxon is right: Let's re-examine our choice for a cap-and-trade system over a carbon tax. *Energy Policy, 37*, 2462-2464.

Wittneben, B., & Kiyar, D. (2009). Climate change basics for managers. *Management Decision, 47*, 1122-1132.

Bios

Chukwumerije Okereke (PhD, University of Keele) is a Reader in Environment and Development at the School of Human and Environmental Sciences, University of Reading, UK. Previously, he was a Senior Reseach Fellow and the head of the Clmate and Development Centre at the Smith School of Enterprise and the Environment, University of Oxford. His research focuses on the links between global climate governance systems and international development. His recent research has addressed the drivers for corporate climate strategies among UK energy intensive companies and the relationship between government policy and corporate carbon management. He has published widely on the political economy and ethical dimensions of the international climate governance regime in journals such as the *California Management Review, Nature, European Management Journal, Global Environmental Change,* and *Global Environmental Politics*.

Bettina Wittneben (PhD, University of Cambridge) received her MBA from the University of Alberta and master of management (diplome d'études supérieures en management) from the Ecole Supérieure de Commerce de Grenoble. She conducted her PhD thesis research at McGill University and the Judge Business School (Cambridge) on institutional change in the transfer of climate-friendly technology. For this work she was awarded the Emerald/EFMD Outstanding Doctoral Research Prize. She has consulted for the UN climate secretariat and the German, UK, and EU governments on climate policy. Most recently, she has researched international climate governance at the University of Oxford. She continues to be a visiting fellow there. She is the Founder of the Wittneben Institute for Sustainable Enterprise. Her work has been published in *Energy Policy*, *Nature*, *Organization Studies*, and *Management Decision*.

Frances Bowen (PhD, University of Bath), holds a chair in innovation studies at the School of Business and Management, Queen Mary, University of London. Her research focuses on innovation for sustainability, particularly in large energy companies. Her recent research has addressed core themes within business responses to climate change, including carbon accounting and the discourse around carbon capture and storage demonstration projects. She has published widely on environmental and social strategy in journals such as the *Journal of Management Studies*, *Entrepreneurship: Theory and Practice*, *British Journal of Management*, and *Journal of Business Ethics.*

Annex 537

S. Chava, “Environmental Externalities and Cost of Capital”, *Management Science*, 2014, pp. 1-25

MANAGEMENT SCIENCE
Articles in Advance, pp. 1–25
ISSN 0025-1909 (print) | ISSN 1526-5501 (online)

http://dx.doi.org/10.1287/mnsc.2013.1863

Environmental Externalities and Cost of Capital

Sudheer Chava
Scheller College of Business, Georgia Institute of Technology, Atlanta, Georgia 30309, sudheer.chava@scheller.gatech.edu

I analyze the impact of a firm's environmental profile on its cost of equity and debt capital. Using implied cost of capital derived from analysts' earnings estimates, I find that investors demand significantly higher expected returns on stocks excluded by environmental screens (such as hazardous chemical, substantial emissions, and climate change concerns) compared to firms without such environmental concerns. Lenders also charge a significantly higher interest rate on the bank loans issued to firms with these environmental concerns. I provide evidence that the environmental profile of a firm is not simply proxying for an omitted component of its default risk. Further, firms with these environmental concerns have lower institutional ownership and fewer banks participate in their loan syndicate than firms without such environmental concerns. These results suggest that exclusionary socially responsible investing and environmentally sensitive lending can have a material impact on the cost of equity and debt capital of affected firms.

Keywords: environmental externalities; financial institutions; banks; cost of capital; finance; investment
History: Received February 17, 2012; accepted July 31, 2013, by Brad Barber, finance. Published online in *Articles in Advance*.

1. Introduction

Over the last two decades, there has been a tremendous increase in capital devoted to socially responsible investing (SRI) that attempts to screen stocks based on undesirable characteristics such as the nature of a business, the amount of pollution, and climate change concerns. In parallel, there has been a marked increase in environmentally sensitive lending that attempts to consider the environmental impact of borrowers in the lending decision. In this paper, I analyze the impact of such environmentally sensitive investing and lending on the cost of equity and debt capital of the affected firms.

Investor tastes for assets as consumption goods can affect asset prices, as highlighted by Fama and French (2007). In particular, investor tastes and preferences for socially responsible investing can affect asset prices. If a sufficiently large number of shareholders abstain from investing in firms based on their environmental concerns, the expected return for these excluded firms can increase (Merton 1987, Heinkel et al. 2001, Gollier and Pouget 2009). Similarly, if a large number of lenders abstain from lending to firms with environmental concerns, and if these firms cannot easily switch to alternate sources of financing, the affected firms could end up paying higher interest rates on their bank loans. In line with these theoretical arguments, in this paper, I find that the environmental profile of a firm significantly affects its cost of equity and debt capital.

The amount of money devoted to SRI has increased steadily over the last few years, with a growth of 324% over the 1995–2007 time period and over 50 times in the last 20 years. The Social Investing Forum reports that $1 in every $8 ($3.07 trillion out of $25.1 trillion under management in the United States, as of 2010) is under SRI guidelines. In addition to screening out undesirable stocks, investors can attempt to influence the environmental policies of firms through shareholder proposals and lobbying the management.[1]

In parallel to this trend in SRI, there has been a substantial increase in the number of lenders considering social and environmental issues in their lending decisions. A large number of banks, representing approximately 80% of the global lending volume, have adopted the Equator Principles (http://www.equator-principles.com/), are signatories to the United Nations Environment Programme's Statement by Banks, and have agreed to consider social and environmental issues in project finance. Cogan (2008) reports that many large, publicly traded banks across the world have started to incorporate climate change concerns in their lending decisions, with some banks (such as the Bank of America) explicitly stating a target for reducing greenhouse gas emissions in their lending

[1] For example, Investor Network on Climate Risk (https://www.ceres.org/incr) represents institutional investors managing $9.5 trillion of assets and aims to leverage their collective power to promote improved disclosure and corporate governance practices on the business risks and opportunities posed by climate change. Landier and Nair (2009) report that during 2007, 331 of 1,150 shareholder resolutions that were filed were socially oriented.

portfolio.[2] Cogan (2008) also reports that 29 of the 40 banks in his survey are involved in clean energy and renewable energy lending.

Similar to SRI, lenders, as publicized, can be motivated by social responsibility. Lenders can also be sensitive to the environmental profile of a firm because of the potential for regulatory, compliance, and litigation risk for the borrower, which can lead to a higher credit risk. In addition, lenders can directly face two additional risks by lending to firms with environmental concerns: lender liability laws that can expose the lender to litigation risk and reputation risk stemming from association with polluting firms (and hence not conforming to prevailing social attitudes that are critical of polluting firms).[3]

Bank debt is an important source of debt financing even for large public companies (Houston and James 1996). If a significant number of lenders adopt environmentally sensitive lending policies, it could have an impact on the cost of debt capital of the borrowers. Some lenders could refrain from lending to a firm based on its environmental profile, either for social responsibility considerations or to avoid the potential lender liability and reputation risk. But some other lenders may price the risk and charge a higher interest rate on loans issued to firms with environmental concerns to compensate for the potential liability and reputation risk they get exposed to by lending to these firms.

The environmental profile of a firm encompasses two broad areas of concerns and strengths. One area includes environmental issues that are already regulated and are required to be reported by the U.S. government (e.g., the emission of toxic chemicals and hazardous waste). The other area includes environmental strengths and concerns in areas that are not yet regulated by the government but where there is a possibility of future regulation. Emissions of greenhouse gases and the carbon footprint of a firm fall into this category. In this paper, I analyze the relationship between a firm's strengths and weaknesses in both these dimensions and its cost of equity and debt capital.

I use the implied cost of capital (ICC) computed from analysts' earnings estimate as a proxy for the ex ante expected stock returns. Gebhardt et al. (2001), Pastor et al. (2008), and Chava and Purnanandam (2010) highlight the advantages of using the ICC as a proxy for expected returns instead of realized returns.[4] The abnormal realized returns to SRI are not clear (e.g., using different sample periods, Statman and Glushkov 2008 find no difference, Brammer et al. 2006 find underperformance, and Kempf and Osthoff 2007 find higher performance). Furthermore, the relatively short time period for which firm-level environmental profile data are available makes the ICC (which relies more on cross-sectional variation across firms) an attractive proxy for expected returns compared to realized returns. In addition, unlike measuring abnormal performance using realized returns, the ICC does not depend on a particular asset pricing model.

Using the ICC computed from the analysts' estimates, I find that there is a statistically and economically significant positive relationship between the net environmental concerns of a firm and the expected returns on its stock. In contrast, there is no meaningful relationship between expected returns and the number of environmental strengths of a firm. In a similar vein, investors seem to demand a significantly higher return on stocks of firms that have a higher climate concern score (defined as climate change concern score minus clean energy strength).

Investors expect significantly higher returns from stocks of firms that are significant emitters of toxic chemicals, firms with hazardous waste concerns, and those with climate change concerns. In contrast, firms that derive substantial revenue from environmentally beneficial products or have pollution prevention strengths do not have a lower ICC, but firms that derive substantial revenues from clean energy products seem to have a lower ICC (in the specification without industry fixed effects).

Moving on to the cost of debt capital, using a large sample of bank loans issued to domestic firms, I find that firms that have net environmental concerns (more environmental concerns than environmental strengths) are charged a higher interest rate on their bank loans. Closer analysis of the individual environmental concerns shows that banks seem to be concerned about both environmental issues that

[2] Citigroup Inc., JPMorgan Chase & Co., and Morgan Stanley say they have produced the Carbon Principles together with several large power companies, Environmental Defense and the Natural Resources Defense Council, that will make it more difficult for new U.S. coal-fired power plants to secure financing. The focus of the principles will be to steer power companies away from plants that emit high levels of carbon dioxide (a greenhouse gas) and to focus on new, cleaner, and renewable technologies (Carbon Principles 2008).

[3] "Faced with mounting pressure from protest groups, 10 of the world's leading banks have agreed to adhere to international environmental and social-impact standards when financing dams, power plants, pipelines and other infrastructure projects" (Phillips and Pacelle 2003). "After years of legal entanglements arising from environmental messes and increased scrutiny of banks that finance the dirtiest industries, several large commercial lenders are taking a stand on industry practices that they regard as risky to their reputations and bottom lines" (Zeller 2010).

[4] In a recent paper, Tang et al. (2013) contrast the ICC computed using the Gebhardt et al. (2001) procedure with alternate methods and suggest that the Gebhardt et al. (2001) method is probably among the best accounting-based expected return models.

are already regulated (such as hazardous waste and substantial emissions of toxic chemicals) and environmental concerns that are not yet regulated (such as concerns related to greenhouse gases or other climate change concerns).

Firms that derive substantial revenues from environmentally beneficial products or services seem to have lower interest rates on their bank loans. Interestingly, consistent with Fisher-Vanden and Thorburn (2011), and similar to the ICC results, lenders do not seem to attach much importance to a firm being signatory to Ceres or the firm being an effective communicator of its environmental record.

Ultimately, in both the cost of equity and debt capital analysis, the alternate explanation to SRI and environmentally sensitive lending is that the environmental profile of a firm is correlated with some omitted component of firm risk. It is a challenging task to conclusively rule out that some omitted (and possibly unobservable) firm-specific risk is driving the results. But I present some ex post evidence (using firm bankruptcies, covenant violations, and rating downgrades) that alleviates this omitted risk concern by showing that at least the environmental profile of a firm is not simply proxying for an omitted component of its default risk. A conservative interpretation of the results is that default risk is not exclusively driving the observed relationship between a firm's environmental profile and its cost of equity and debt capital.

Furthermore, I provide supporting evidence that SRI and environmentally sensitive lending may be responsible for the higher cost of equity and debt capital for firms with environmental concerns. I document that such firms with environmental concerns indeed have a lower percentage of institutional ownership and fewer institutional owners hold their shares. In particular, I show that firms with hazardous waste and climate change concerns have significantly lower institutional ownership. I find similar results for the number of institutional owners of a firm's stock. The higher expected returns and lower institutional ownership in stocks with environmental concerns are consistent with the theoretical arguments in Merton (1987), Heinkel et al. (2001), and Gollier and Pouget (2009). I also find that the effect of environmental concerns on norm constrained institutional holdings and expected returns is stronger in the recent time period compared to the early part of the sample. These findings are in line with the increase in environmental sensitivity over time.

I next show that fewer banks participate in the loan syndicate of borrowers with environmental concerns. There is no meaningful relationship between loan syndicate size and the number of environmental strengths of a firm. This suggests that some lenders may be avoiding lending to firms with environmental concerns, especially, firms with substantial emission concerns. There is weak evidence of more banks lending to firms that derive substantial revenue from environmentally beneficial products. In general, lenders seem to avoid firms with environmental concerns but may not necessarily be flocking to firms with environmental strengths.

The negative relationship documented between institutional ownership (loan syndicate size) and a firm's environmental concerns is consistent with the positive relationship documented between the ICC (loan spreads) and firm's environmental concerns (Merton 1987, Heinkel et al. 2001). Taken together, these results suggest that SRI and environmentally sensitive lending are having an impact on the cost of capital of affected firms.

If SRI and environmentally sensitive lending lead to a significantly higher cost of equity and debt capital for firms with environmental concerns, the affected firms may internalize their environmental externalities. For example, hazardous waste and toxic emissions may be a natural by-product of a firm's business (say utilities or chemical companies). But firms can choose among various combinations of raw input material (such as fuel type), technology (including abatement technology), installation of additional pollution prevention equipment (such as scrubbers), and so forth, which can affect the amount and constitution of various pollutants. If the cost of capital increases sufficiently for firms adopting a polluting technology, firms may rationally switch to less polluting albeit more expensive technology (see Heinkel et al. 2001 and recent evidence in Holladay 2010 that polluters react to new environmental regulations by abating rather than relocating to avoid regulations).

These findings contribute to the literature on investor and lender reaction to a firm's environmental and social externalities. Hong and Kacperczyk (2009) show that sin stocks (tobacco, alcohol, and gambling) have higher realized equity returns and are held less by norm-constrained institutions. In contrast, I use the ICC as a proxy for expected returns but, more importantly, I consider the environmental profile of a firm, as opposed to its nature of business. Firms can change their environmental profile but sin stocks, by definition, cannot change their line of business. In addition, unlike Hong and Kacperczyk (2009), I consider whether the environmental profile of a firm affects its bank loan spreads. Fisher-Vanden and Thorburn (2011) find that there is no abnormal stock reaction to a firm's announcement to join voluntary initiatives such as Ceres. In line with their findings, I find that voluntary environmental initiatives do not reduce the cost of equity or debt capital.

My paper is also related to studies that examine the relationship between corporate social responsibility (CSR) and cost of capital. El Ghoul et al. (2011)

find that firms with better CSR scores exhibit cheaper equity financing where as participation in two sin industries, namely, tobacco and nuclear power, increases firms cost of equity. Derwall and Verwijmeren (2007), Sharfman and Fernando (2008), and Goss and Roberts (2011) analyze the cost of capital implications of CSR. Bauer and Hann (2010) study the relationship between corporate bond spreads and the environmental profile of the firm. Gillan et al. (2010) analyze why firms typically adopt stronger environmental, social, and corporate governance policies and the extent to which the market values or trades on these decisions. Fernando et al. (2010) examine how ownership, analyst coverage, and the valuation of firms vary with their environmental performance. I complement these studies by looking at the impact of the environmental profile of the firm on the cost of equity and debt capital and provide some supportive evidence that socially responsible investing and environmentally responsible lending are responsible for the increase in the cost of capital of affected firms. In addition, by analyzing the incidence of firm bankruptcies, covenant violations, and credit rating downgrades in firms with environmental concerns, I present evidence that default risk is not exclusively driving the observed relationship between the cost of capital and the environmental profile of the firm.

The remainder of this paper is organized as follows. Section 2 explains the data sources and variable construction. Section 3 presents the empirical results. Section 4 explores why investors and lenders may take into account the environmental profile of a firm. Section 5 concludes the paper.

2. Data

The data used in the analysis fall into four major categories: (1) data on the environmental profile of the firm, (2) data on analyst estimates for the ICC calculations, (3) bank loan data, and (4) accounting and market data required to compute the control variables. Below, I describe each data source in detail and outline the construction of the variables used in this paper. The descriptive statistics are presented in Online Appendix C (available at http://www.prism.gatech.edu/~schava6/).

2.1. Data: Environmental Profile of the Firm

The data source for the firm-level environmental profile is KLD Stats. This database has information on environmental concerns and environmental strengths for a large sample of firms rated by KLD Research & Analytics, Inc., now a part of MSCI. There are other data sources, such as a firm's 10-K reports, carbon data project, and so forth, with information on some of the environmental variables I am interested in. But, currently, environmental profile disclosure is not uniform and when firms do report, for example, emissions, it is difficult to evaluate and quantify the risk implied by these numbers. In contrast, KLD collects this information from a number of data sources and their analysts evaluate the data to decide whether a firm has a specific environmental exposure or not. KLD data are also available for a larger cross section of firms and for a much longer time span than I would be able to gather from any alternate data sources. More importantly, it is necessary for me to use a database that a large number of SRI investors use as a source for their environmental screens. KLD publishes a number of environmental, social, and governance (ESG) indices, including MSCI KLD 400 social index, and a vast majority of the top 50 institutional money managers worldwide use their research to integrate ESG factors into their investment decisions. Recent papers that have used this database include Hong and Kacperczyk (2009) and Fisher-Vanden and Thorburn (2011).

KLD database expanded its coverage over the years starting with S&P 500 firms during 1991–2000, expanding to Russell 2000 firms starting in 2001. The sample period is 1992–2007[5] except when mentioned otherwise. (Some environmental profile variables are available from a later date.) The KLD database divides the environmental profile of a firm into two components: environmental strengths and environmental weaknesses.

2.1.1. Environmental Concern Measures. I consider three individual environmental concerns[6] from the KLD database, each coded as one if the firm is exposed to that particular environmental concern during the year and zero otherwise: *hazardwaste*, *subemissions*, and *climchange*. Here, *hazardwaste* is a dummy variable that is coded as one if the company's liabilities for hazardous waste sites exceed $50 million or if it has recently paid substantial fines or civil penalties for waste management violations. The variable *subemissions* is coded as one if the company's legal emissions of toxic chemicals (as defined by and reported to the Environmental Protection Agency (EPA)) from individual plants into the air and water are among the highest of the companies followed by KLD. The variable *climchange* (available since 2000) is a dummy variable that is coded as one if the company derives

[5] I restrict the data to 1992–2007 to exclude the financial crisis of 2008, but the results remain similar even if I extend the data to include 2008.

[6] KLD also assigns values for some other concerns (e.g., ozone depletion), which I do not consider separately because they are sparsely populated. However, these are included in the environmental concerns index computed by KLD, *numconcerns*, that I use in the analysis.

substantial revenues from the sale of coal or oil and its derivative fuel products or indirectly from the combustion of coal or oil and its derivative fuel products (such companies include electric utilities, transportation companies with fleets of vehicles, automobile and truck manufacturers, and other transportation equipment companies).

2.1.2. Environmental Strength Measures. I consider four individual environmental strengths available in the KLD database, each coded as one if the firm is considered to have strength in that particular environmental dimension during the year, and zero otherwise: *benproduct*, *polprevent*, *cleanenergy*, and *envcomm*. The variable *benproduct* is a dummy that takes the value of one if the company derives substantial revenues from innovative remediation products, environmental services, or products that promote the efficient use of energy, or if the company has developed innovative products with environmental benefits. But this does not include services with questionable environmental effects, such as landfills, incinerators, waste-to-energy plants, and deep injection wells. The variable *polprevent* is coded as one if the company has notably strong pollution prevention programs, including both emission reductions and toxic-use reduction programs. The variable *cleanenergy* is coded as one if the company has taken significant measures to reduce its impact on climate change and air pollution through the use of renewable energy and clean fuels or through energy efficiency or if the company has demonstrated a commitment to promoting climate-friendly policies and practices outside its own operations. Finally, *envcomm* (available since 1997) is a dummy variable that is coded as one if the company is a signatory to the Ceres Principles, publishes a notably substantive environmental report, or has notably effective internal communications systems in place for environmental best practices.

2.1.3. Summary Measures of Environmental Concerns and Strengths. In addition to the individual concerns and strengths described earlier in this section, the KLD database also provides a count of the total number of environmental concerns (*numconcerns*) and the total number of environmental strengths (*numstrength*) for a firm. I also construct a net measure of environmental concerns (*netconcerns*) defined as *numconcerns-numstrength* and a measure of exposure to climate change, *climscore*, defined as *climchange-cleanenergy*.

2.2. Data: ICC

2.2.1. Analyst Estimates for ICC Computation. The Institutional Brokers' Estimate System (I/B/E/S) database is the source for analyst consensus estimates for one- and two-year-ahead forecast of earnings per share[7] and long-term consensus growth forecast required to compute the ICC used as a proxy for expected returns. The ICC is computed as the internal rate of return that equates the present value of free cash flows to equity to current stock price. I closely follow Gebhardt et al. (2001), Pastor et al. (2008), and Chava and Purnanandam (2010) for the construction of the ICC measure. The details of the ICC construction are given in Appendix A. I estimate the ICC for every firm covered in the intersection of KLD, CRSP, Compustat, and I/B/E/S databases as of June 30, starting from 1992, and ending in 2007. I subtract the risk-free rate based on a one-year Treasury yield at that time to obtain a measure of the expected excess return on the stock.

2.2.2. Control Variables in ICC Regressions. The specification for the ICC regressions is based on Gebhardt et al. (2001), Pastor et al. (2008), and Chava and Purnanandam (2010). In cross-sectional studies, Gebhardt et al. (2001) find robust relationship between cost of capital and some firm-level attributes such as size and book-to-market ratio. Pastor et al. (2008) provide evidence in support of a positive relationship between expected market return and volatility. Chava and Purnanandam (2010) control for past stock returns to account for any staleness in analyst forecasts and show that the past stock return is a significant predictor of the expected return on the stock. Based on these papers, I include the following firm-level variables in the regressions: firm size measured as the log of the firm's book assets (*logta*), market-to-book ratio of the firm (*mtb*), book leverage (*lever*), stock return volatility of the firm over the past one year (*stdret*), and past one month's stock return of the firm ($ret_{t-1,t}$). The sources of firm characteristics is Standard and Poor's quarterly Compustat database. Market data are from the Center for Research in Security Prices (CRSP). All financial data are lagged by at least six months so that they are available at the time of the ICC construction (June 30 of each year). Furthermore, all financial data are winsorized at 1% and 99% to handle outliers.

2.3. Data: Cost of Debt Capital

2.3.1. Bank Loan Data. Data on bank loans are obtained from the Dealscan database distributed by the Loan Pricing Corporation. Dealscan contains information on approximately 106,000 facilities to domestic companies, out of which approximately 50,000 facilities can be linked to firm-level balance sheet information in Compustat. (See Chava and Roberts 2008

[7] Kumar (2010) and Jiang et al. (2010) find that some of the differences in individual analysts forecasts can be attributed to their gender and political preferences. Using the consensus forecasts of the analysts should mitigate some of the concerns regarding biases in individual analyst forecasts.

for details on matching Dealscan with Compustat.) After merging these data with the KLD database, I am left with 5,879 bank loans to nonfinancial firms during 1992–2007. This drop in the sample size is mainly attributable to dropping financial firms, the sample of firms covered by KLD Stats, and the sample period.

The key interest rate variable is the log of the loan spread *aisd*. Similar to Chava et al. (2009) and Acharya et al. (2013), I obtain *aisd* (all-in-spread-drawn) from the Dealscan database. This measures the amount the borrower pays in basis points over London Interbank Offered Rate (LIBOR) for each dollar drawn down. It adds the spread of the loan with any annual fees (or facility fee) paid to the bank group.

2.3.2. Control Variables in Bank Loan Regressions. The source of firm characteristics is Standard and Poor's quarterly Compustat database. Market data are from CRSP. All financial data are lagged by at least six months so that they are available at the time of loan pricing. Further, all financial data are winsorized at 1% and 99% to handle outliers.

I use the following firm-level control variables based on Bradley and Roberts (2003) and Chava et al. (2009) in the loan spread regressions. Here, *logasset* measures the natural logarithm of the total assets of the firm extracted from Compustat. The variable *opincbefdep_a* is the ratio of operating income before depreciation to the total assets of the firm. The variable *lever* measures the leverage of the firm constructed as the ratio of total debt (sum of long-term- and short-term debt) scaled by the total assets of the firm. The variable *modzscore* is the modified *z*-score without leverage. The variable *unrated* is a dummy variable that is coded as one if the firm does not have a public debt rating and zero otherwise; and *Invgrade* is a dummy variable that is coded as one if the firm has public debt rated investment grade from Standard & Poor's and zero otherwise.

I control for the following loan specific features in the regression: *maturity* is defined as the number of months between loan inception and loan end date, *perfprice* is a dummy variable that is coded as one if the loan has a performance pricing feature and zero otherwise, and *termloan* is a dummy variable that is coded as one if the loan is a term loan and zero otherwise. I do not control for loan size since it is highly correlated with firm size, but controlling for loan size does not have a material impact on the results.

The regressions also include the following macro variables: *termspread*, constructed as the difference in yields between ten-year and one-year Treasury notes, and *creditspread*, constructed as the difference in yields between BAA and AAA corporate bonds.

3. Empirical Results

I present the results of the empirical analysis in this section. I first consider aggregate measures of a firm's environmental profile, followed by the individual environmental concerns and then the individual environmental strengths of a firm. I first present the impact of each particular environmental profile variable on the cost of equity capital, followed by the impact on bank loan pricing. I include the environmental variables one at a time. Including all of the firm's environmental profile variables simultaneously reduces the sample period to only 2000–2007 instead of 1992–2007 (since some of the variables are available for a shorter period of time, e.g., climate change from 2000 onward). But the results remain qualitatively similar if I restrict attention to only the 2000–2007 sample period and include all the individual environmental strengths and concerns in one specification.

In the ICC analysis, I estimate panel regressions with the expected excess return on the firm as the dependent variable and environmental concerns and strengths as the key explanatory variables. The regressions include firm-level control variables and year fixed effects, with standard errors clustered at the firm level. I estimate specifications with and without industry fixed effects at the two-digit Standard Industrial Classification (SIC) level. I do not use firm fixed effects in light of the persistence of the key environmental concern and strength variables. In unreported tests, I also estimate a Fama–MacBeth regression model with annual cross-sectional regressions every year with correction for autocorrelations up to two lags in computing the standard errors. The results are essentially the same, but I decided to report the panel regressions, given the short time series available for some of the environmental variables.

To analyze the impact of the environmental concerns and strengths of firms on loan pricing, I regress the log of the all-in-drawn spread (*logaisd*) on various measures of environmental strengths and concerns and other control variables. The control variables include firm-specific variables, loan-specific variables, and macro variables. The regressions also include year fixed effects, and dummies for loan purpose indicators. I also report specifications with and without industry fixed effects based on two-digit SIC codes to make sure that industry affiliation is not the main source of the results. All standard errors are clustered at the firm level to account for correlation across multiple observations of the same firm. I do not use firm fixed effects, since the environmental variables are highly persistent.

3.1. Aggregate Measures of Environmental Concerns and Strengths and the Cost of Capital

I first present the results relating environmental concerns and strengths indices with the cost of equity capital. Next, I present bank loan pricing results.

Table 1 Impact of Environmental Concerns and Strength Indices on Expected Stock Returns

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
netconcerns	0.1726	0.1298						
	(4.47)	(3.77)						
numconcerns			0.1762	0.1465				
			(3.95)	(3.81)				
numstrength					−0.0598	−0.0421		
					(−0.93)	(−0.72)		
climscore							0.4804	0.2462
							(4.04)	(2.17)
logta	−0.1549	−0.1519	−0.1207	−0.1310	−0.1665	−0.1632	−0.1585	−0.1581
	(−5.30)	(−5.75)	(−4.20)	(−5.02)	(−5.33)	(−5.97)	(−5.48)	(−5.56)
mtb	−0.1716	−0.0926	−0.1778	−0.0955	−0.1695	−0.0909	−0.1901	−0.0896
	(−7.27)	(−4.24)	(−7.47)	(−4.34)	(−7.16)	(−4.15)	(−7.53)	(−3.58)
lever	0.7323	0.8641	0.7234	0.8515	0.7266	0.8738	1.0200	0.9844
	(3.20)	(3.94)	(3.14)	(3.88)	(3.18)	(3.99)	(4.02)	(4.00)
stdret	2.2680	2.6068	2.3215	2.7278	2.3795	2.6345	2.2757	2.7954
	(2.86)	(3.31)	(2.91)	(3.45)	(3.01)	(3.34)	(2.48)	(3.11)
$ret_{t-1,t}$	−4.7689	−5.1404	−4.7607	−5.1374	−4.7683	−5.1397	−4.4848	−4.9650
	(−15.77)	(−16.19)	(−15.70)	(−16.17)	(−15.76)	(−16.19)	(−12.18)	(−13.02)
R^2	0.220	0.364	0.217	0.363	0.219	0.364	0.191	0.330
N	13,114	13,114	13,114	13,114	13,114	13,114	9,413	9,413
Industry fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Std. error clustering	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm

Notes. This table presents regression results analyzing the impact of summary environmental measures on the expected stock returns. The dependent variable is the expected risk premium calculated as the difference between the ICC and one-year risk-free rate. The sample includes firms in the intersection of CRSP, Compustat, KLD, and I/B/E/S during 1992–2007. Appendix A contains the details of the ICC construction. Variable definitions are given in Appendix B. Robust t-statistics adjusted for firm-level clustering are presented in parentheses.

3.1.1. Expected Stock Returns. I analyze the relationship between expected stock returns as proxied by the ICC and various summary measures of environmental strengths and concerns in Table 1. The results in Model 1 indicate that the investors expect significantly higher returns for firms that have higher net environmental concerns (net of environmental strengths). Investors expect 1.38% per annum higher than the risk-free rate from a firm that has environmental concerns on all four dimensions considered compared with firms that have environmental strengths on all dimensions.[8] The relationship is statistically significant and economically meaningful, indicating that the environmental profile of a firm matters to investors. Inclusion of industry fixed effects at the two-digit SIC level in Model 2 reduces the coefficient estimate of *netconcerns* and its statistical significance marginally, but the estimate is still statistically significant.

In Models 3 and 4, the key explanatory variable is the number of environmental concerns of a firm. The results demonstrate that there is a significant positive relationship between the ICC and number of environmental concerns of a firm, in line with the theoretical predictions of Heinkel et al. (2001). If a significant number of socially responsible investors screen out stocks with environmental concerns, then the expected returns on these stocks could go up. The results in Models 3 and 4 suggest that investors expect approximately 0.7% per annum *higher* for firms that have environmental concerns in all dimensions (almost 18% higher compared with the median firm).[9]

Models 5 and 6 document that there is no meaningful relationship between the number of environmental strengths and expected stock returns. This is in contrast to the strong positive relationship between environmental concerns and expected stock returns, suggesting that while investors may be screening out stocks with environmental concerns, they are not necessarily flocking to stocks with environmental strengths.

[8] The maximum value for environmental concerns in the sample is 4 and the maximum value for environmental strengths in the sample is also 4. So, based on the parameter estimate of 0.1726, investors expect 1.38% ($0.1726 * 8$) per annum higher than the risk-free rate from a firm that has environmental concerns on all four dimensions compared with firms that have environmental strengths on all four dimensions.

[9] The maximum value for environmental concerns in the sample is 4. So, based on the parameter estimate of 0.1762, investors expect 0.7% ($0.1762 * 4$) per annum higher than the risk-free rate from a firm that has environmental concerns on all four dimensions.

In Models 7 and 8, the key environment variable is *climscore*, defined as the difference between climate change concern and clean energy strength. This variable measures the net exposure of a firm to the climate change concerns and is only available since 2000. In line with the results in Models 3 and 4, there is a very strong positive relationship between net climate change concerns and the ICC. Investors seem to demand a significantly higher return from firms that are more exposed to climate change concerns. The results are economically significant, representing 0.96% per annum higher expected returns for firms that have climate change concerns compared with firms that have clean energy strength. The inclusion of industry fixed effects significantly reduces the strength of this relationship, but this is not surprising, given that climate change concerns and clean energy are mostly defined at the industry level.

In all of the models, the coefficients of the control variables are in the expected direction and consistent with the previous literature. Small firms have a significantly higher cost of capital, and firms with higher leverage have higher expected returns. More volatile firms have higher expected returns and there is a significant negative relationship between expected returns and the past one month's stock returns. These results are consistent with the previous literature (e.g., Gebhardt et al. 2001, Chava and Purnanandam 2010).

3.1.2. Bank Loan Spreads. I document the relationship between bank loan spreads and summary measures of the environmental profile of firms in Table 2. In Model 1, the key explanatory variable is net environmental concerns (*netconcerns*). The dependent variable is the log of the all-in-drawn loan spread over the LIBOR. As the results indicate, the higher the net environmental concerns (i.e., more environmental concerns than environmental strengths) of a firm, the higher its bank loan spread. The relationship is both economically and statistically significant. I include industry fixed effects in Model 2 and, as expected, the magnitude of the coefficient of *netconcerns* decreases but is still significant. A firm that has environmental concerns in all dimensions considered pays an almost 20% higher loan interest rate (approximately 25 bps) compared with a firm that has an equal number of environmental concerns and strengths.

Table 2 Impact of Environmental Concerns and Strength Indices on Bank Loan Spreads

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
netconcerns	0.0502 (3.24)	0.0535 (3.01)						
numconcerns			0.0518 (3.05)	0.0606 (3.07)				
numstrength					−0.0360 (−1.06)	−0.0448 (−1.31)		
climscore							0.0503 (1.28)	0.0276 (0.62)
logasset	−0.1890 (−11.69)	−0.1992 (−11.79)	−0.1926 (−11.95)	−0.2043 (−11.97)	−0.1748 (−11.61)	−0.1860 (−11.47)	−0.1697 (−9.85)	−0.1821 (−10.06)
opincbefdep_a	−6.5311 (−10.01)	−6.5168 (−10.70)	−6.5069 (−9.93)	−6.5095 (−10.65)	−6.6436 (−10.21)	−6.6066 (−10.78)	−6.5271 (−9.66)	−6.3171 (−10.04)
lever	0.4901 (4.39)	0.5177 (4.71)	0.4872 (4.39)	0.5198 (4.70)	0.4892 (4.36)	0.5157 (4.68)	0.3788 (3.33)	0.4258 (3.78)
modzscore	−0.2086 (−7.67)	−0.1707 (−5.81)	−0.2075 (−7.61)	−0.1694 (−5.75)	−0.2158 (−7.85)	−0.1739 (−5.92)	−0.2330 (−8.27)	−0.1804 (−6.04)
unrated	−0.2178 (−4.94)	−0.2462 (−5.68)	−0.2197 (−4.97)	−0.2488 (−5.73)	−0.2084 (−4.71)	−0.2355 (−5.41)	−0.1745 (−3.87)	−0.2118 (−4.59)
invgrade	−0.6684 (−14.50)	−0.6737 (−15.43)	−0.6719 (−14.55)	−0.6756 (−15.53)	−0.6618 (−14.10)	−0.6739 (−15.41)	−0.6554 (−13.64)	−0.6742 (−13.94)
R^2	0.632	0.719	0.632	0.718	0.630	0.717	0.610	0.690
N	5,879	5,879	5,879	5,879	5,879	5,879	4,602	4,602
Industry fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
Loan-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Std. error clustering	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm

Notes. This table presents regression results relating bank loan spreads and aggregate environmental concerns and strength variables. The dependent variable is the log of the all-in-drawn spread on the loan. The sample includes firms in the intersection of CRSP, Compustat, KLD, and Dealscan during 1992–2007. Variable definitions are given in Appendix B. Loan-level controls include *loan purpose indicators*, *maturity*, *perfprice*, and *termloan*. Macro controls include *termspread* and *creditspread*. The *t*-statistics are given in parentheses below the estimates and are adjusted for firm-level clustering.

The results in Models 3 and 4 show that banks charge firms with environmental concerns a higher loan interest rate. If a firm has environmental concerns in all dimensions considered, then the regression coefficients indicate that lenders charge the firm around 25 bps higher than a firm with no environmental concerns. Given that the average loan size is around $568 million, this increase in cost of debt capital is significant for firms with environmental concerns. In addition, taken together with the results in Models 1–4 of Table 1, it appears that both stock investors and lenders take into account the environmental concerns of a firm.

The results in Models 5 and 6 show that firms with a higher number of environmental strengths are charged lower loan interest rates on their bank loans but the relationship is not statistically significant. Models 5 and 6 of Table 1 show similar results in the ICC regressions. It seems investors and lenders attach much more importance to the environmental concerns of a firm but not so much to its environmental strengths. The coefficient of *climscore* is positive but not statistically significant in Models 7 and 8 of Table 2, indicating that lenders are not pricing the net climate exposure of a firm. These results differ from the significant relationship between the ICC and net climate exposure documented in Models 7 and 8 of Table 1. Stock investors and lenders may differ on the importance of a firm's climate change exposure but it is also likely that the smaller sample size in the bank loan regressions is causing the results. I analyze the constituents of *climscore* in more detail in later subsections.

The coefficients of the control variables in all of the models are in the expected direction and consistent with the prior literature (Bradley and Roberts 2003, Chava et al. 2009). Larger firms and more profitable firms have lower loan spreads, whereas firms with higher leverage have higher loan spreads. As expected, firms that are farther from financial distress (higher *modzscore*) pay lower loan interest rates. Compared with firms that are rated noninvestment grade, firms with investment-grade rating and unrated firms pay lower loan spreads. In the interest of space, I do not present the estimates on the loan-specific and macro control variables, but the results are in line with the literature. Among the loan-specific features, longer maturity loans are associated with lower loan spreads, and term loans have a higher loan spread (compared to revolvers). Performance pricing clauses do not seem to affect loan spreads significantly. The macro economic variables credit spread and term spread do not seem to be significantly related to the loan spreads, probably because of the inclusion of the year fixed effects. Not surprisingly, industry seems to matter for loan spreads, with the magnitude and significance of the coefficients of the environmental profile variables decreasing once industry effects are included.

3.2. Individual Environmental Concerns and the Cost of Capital

In this subsection, I first present the results relating individual environmental concerns with the cost of equity capital. Next, I present bank loan pricing results.

3.2.1. Expected Stock Returns. In Table 3, I analyze the relationship between the individual environmental concerns of a firm and expected returns on its stock. The regression specification remains the

Table 3 Impact of Environmental Concerns on Expected Stock Returns

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
hazardwaste	0.2673	0.2338				
	(2.30)	(2.38)				
subemissions			0.2922	0.1801		
			(2.35)	(1.72)		
climchange					0.6879	0.4777
					(4.34)	(2.75)
R^2	0.218	0.363	0.218	0.363	0.191	0.331
N	13,114	13,114	13,114	13,114	9,413	9,413
Firm-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Std. error clustering	Firm	Firm	Firm	Firm	Firm	Firm

Notes. This table presents regression results analyzing the impact of individual environmental concerns on the expected stock returns. The dependent variable is the expected risk premium calculated as the difference between the ICC and one-year risk-free rate. The sample includes firms in the intersection of CRSP, Compustat, KLD, and I/B/E/S during 1992–2007. Appendix A contains the details of the ICC construction. Firm-level controls include *logta*, *mtb*, *lever*, *stdret*, and $ret_{t-1,t}$. Variable definitions are given in Appendix B. Robust t-statistics adjusted for the firm-level clustering are presented in parentheses.

same as before. The key environmental concern variable in Models 1 and 2 is *hazardwaste*. There is a strong positive relationship between *hazardwaste* and the ICC, suggesting that investors demand a significantly higher stock return (approximately 7% higher) from firms with hazardous waste concerns. The result is robust to the inclusion of industry fixed effects in Model 2.

In Models 3 and 4, *subemissions*, an indicator variable for whether the firm is a substantial emitter of toxic chemicals as reported by EPA, is the key explanatory variable. Again, there is a statistically significant and economically meaningful positive relationship between expected stock returns and substantial toxic chemical emission concerns. The introduction of industry fixed effects in Model 4 decreases the economic and statistical significance of the effect. The coefficient estimates indicate that investors demand 0.18% to 0.29% higher returns per annum on stocks of firms with substantial toxic chemical emission concerns, compared with the stocks of firms with no such concerns.

In Models 5 and 6, I include *climchange*, a dummy variable that measures whether the firm derives substantial revenues from the sale of coal or oil and its derivative products. The variable *climchange* has a significantly positive effect on the expected returns of the firm. The result is robust to the inclusion of industry fixed effects in Model 6. The expected return on the stocks of firms with climate change concerns are 0.47% to 0.69% higher compared with firms with no such concern. Of the individual environmental concerns variables considered, impact of the climate change concerns is the highest.

3.2.2. Bank Loan Spreads. Next, I relate the individual environmental concerns to bank loan spreads to shed light on the specific environmental concerns that the lenders are most concerned about. The results are presented in Table 4. The regression specification is similar to the specification employed in Table 2, with the log of the loan spread as the dependent variable and using loan-level, firm-level, and macro controls. As before, I present regression specifications with and without industry fixed effects separately, but all specifications include year fixed effects.

The results in Models 1 and 2 suggest that banks seem to charge a significantly higher loan spread (12% to 13% higher) for firms with hazardous waste concerns compared with firms without such concerns. The relationship is economically and statistically significant. Models 3 and 4 show that lenders price substantial emissions concerns and charge an approximately 9% to 11% higher spread on loans issued to firms with substantial emissions concerns, compared with firms that have no such concerns. The inclusion of industry effects increases the coefficient estimate and statistical significance.

There seems to be a significant positive relationship between climate change concerns and loan spreads when industry fixed effects are not included in Model 5. However, once the industry fixed effects are included in Model 6, the magnitude of the coefficient drops considerably and the relationship is no longer statistically significant. In light of the limited within-industry variation in the climate change concerns, the results in Model 5 (without industry fixed effects) are

Table 4 Impact of Individual Environmental Concerns on Bank Loan Spreads

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
hazardwaste	0.1229	0.1332				
	(2.74)	(2.76)				
subemissions			0.0904	0.1174		
			(1.90)	(2.36)		
climchange					0.1492	0.0293
					(3.03)	(0.45)
R^2	0.631	0.718	0.630	0.717	0.612	0.690
N	5,879	5,879	5,879	5,879	4,602	4,602
Firm-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	Yes	No	Yes
Loan level controls	Yes	Yes	Yes	Yes	Yes	Yes
Macro variables	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Std. error clustering	Firm	Firm	Firm	Firm	Firm	Firm

Notes. This table presents regression results relating bank loan spreads and individual environmental concern variables. The dependent variable is the log of the all-in-drawn spread on the loan. The sample includes firms in the intersection of CRSP, Compustat, KLD, and Dealscan during 1992–2007. Variable definitions are given in Appendix B. Firm-level controls include *logasset*, *opincbefdep_a*, *lever*, *modzscore*, *unrated*, and *invgrade*. Loan-level controls include *loan purpose indicators*, *maturity*, *perfprice*, and *termloan*. Macro controls include *termspread* and *creditspread*. The t-statistics are given in parentheses below the estimates and are adjusted for firm-level clustering.

still interesting and suggest that firms with climate change concerns pay a higher spread on their bank loans. This is remarkable for a couple of reasons. First, bank loans are relatively short term, with the average maturity of the loans around 3.5 years. It is not likely that the climate change would impact the firm significantly during the life of the loan. Second, there are currently no regulations governing the emissions of greenhouse gases and carbon emissions of firms in the United States; however, some of the lending banks are signatories to Ceres, climate leaders, and equator principles that aim to cut down the greenhouse gas emissions.

The relationship between individual environmental concerns and the ICC (presented in Table 3) and bank loan spreads (presented in Table 4) are largely consistent with each other, with some minor differences depending on whether industry effects are included or not. Stock investors and lenders seem to take into account the environmental concerns of the firm, but not all environment concerns are equally weighed. To address the concern that *hazardwaste* (defined as a dummy that is coded as one if the company's liabilities for hazardous waste sites exceed $50 million or if it has recently paid substantial fines or civil penalties for waste management violations) may be measuring two different issues, I reestimate the regressions after controlling for the variable *regconcerns* (available from KLD), which measures whether the firm has any recent regulatory concerns. Both the ICC and bank loan spread results presented earlier remain similar after controlling for a firm's regulatory concerns, indicating that the relationship is mainly driven by a firm's hazardous waste liability concerns rather than the regulatory penalties paid by that firm.

Interestingly, climate change concerns that proxy for the greenhouse gas emissions and carbon footprint of a firm seem to have the most impact for both the ICC and bank loan spreads (when industry fixed effects are not included) even though they are not yet regulated. With industry fixed effects, the statistical significance in the bank loan spread results disappears, whereas it remains strong in the ICC results (this may be partly explained by the smaller sample in the bank loan analysis with 119 unique firms with the climate change concern compared to 165 unique firms in the ICC analysis). Climate change concerns may matter if socially responsible investors screen out stocks with climate change concerns or because of the anticipated costs of future regulation. The cost of anticipated future regulation may include compliance costs and litigation costs that may arise from the new rules.

3.3. Individual Environmental Strengths and the Cost of Capital

In this subsection, I first present the results relating individual environmental strengths with the cost of equity capital. Next, I present bank loan pricing results.

3.3.1. Expected Stock Returns. Table 5 documents the results from an analysis of expected returns and individual environmental strengths of a firm. The results are presented in Models 1–8, with and without industry fixed effects. Investors seem to expect lower returns from stocks of firms that derive substantial revenue from environmentally beneficial products (Models 1 and 2 of Table 5), but the relationship is not statistically significant. The results in Models 3 and 4 relate expected stock returns and *polprevent*, a dummy

Table 5 Impact of Environmental Strengths on Expected Stock Returns

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
benproduct	−0.2269	−0.2550						
	(−1.33)	(−1.41)						
polprevent			0.2348	0.0956				
			(2.11)	(0.87)				
cleanenergy					−0.4082	−0.0668		
					(−3.22)	(−0.54)		
envcomm							0.2320	0.2098
							(1.23)	(1.31)
R^2	0.218	0.363	0.218	0.363	0.218	0.363	0.222	0.360
N	13,114	13,114	13,114	13,114	13,114	13,114	10,783	10,783
Firm-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Std. error clustering	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm

Notes. This table presents regression results analyzing the impact of environmental strengths on the expected stock returns. The dependent variable is the expected risk premium calculated as the difference between the ICC and one-year risk-free rate. The sample includes firms in the intersection of CRSP, Compustat, KLD, and I/B/E/S during 1992–2007. Appendix A contains the details of the ICC construction. Firm-level controls include *logta*, *mtb*, *lever*, *stdret*, and $ret_{t-1,t}$. Variable definitions are given in Appendix B. Robust t-statistics adjusted for firm-level clustering are presented in parentheses.

variable that takes the value of one for firms that have notably strong pollution prevention programs, including both emission reductions and toxic-use reduction programs. The coefficient of *polprevent* is in fact positive but not statistically significant after the inclusion of industry fixed effects.

The most significant relationship with expected returns among the environmental strength variables is with clean energy environmental strength. Investors demand a significantly lower expected return from firms that have a clean energy environmental strength. The coefficient of *cleanenergy* indicates that after controlling for other firm-specific factors, investors seem to demand 0.4% per annum lower returns from stocks that have a clean energy environmental strength than stocks of firms that do not (almost 10% lower than the median firm in the sample). The inclusion of industry fixed effects eliminates the statistical significance of this measure. This is not surprising given that clean energy is mostly an industry level variable and there is not enough within-industry variation in this measure.

Interestingly, there does not seem to be any meaningful association between firm expected returns and environmental communication (or Ceres signatory) strength. These results are consistent with Fisher-Vanden and Thorburn (2011), who find that there are no significant abnormal returns around firm announcements of joining Ceres. These results seem to indicate that investors do not attach much weight to voluntary environmental initiatives.

3.3.2. Bank Loan Spreads. I consider the relationship between firm individual environmental strengths and loan spreads in this subsection. The results in Models 1 and 2 of Table 6 show that lenders charge significantly *lower* spreads for firms that derive substantial revenues from environmentally beneficial products. The relationship is highly significant both statistically and economically. Firms that are considered strong in this dimension pay approximately 20%, or 25 bps, lower spreads compared with firms that do not have this flag. So, there is a lower cost of equity and debt capital for firms with *benproduct* environmental strength, even though the relationship in the equity market is not statistically significant.

The results in Models 3 and 4 (Models 5 and 6) show that there is no statistically significant relationship between loan spreads and pollution prevention program indicators (*cleanenergy*). These results are in contrast with the lower expected stock return (without industry effects) for firms with *cleanenergy* strength documented in Model 5 of Table 5. Similar to the ICC results in Models 7 and 8 of Table 5 and consistent with Fisher-Vanden and Thorburn (2011), Models 7 and 8 of Table 6 show that bank loan spreads are not affected by the borrower being a signatory to voluntary environmental initiatives.

Overall, the only individual environmental strength variable that has a statistically significant relationship with bank loan spread is *benproduct*. The other environmental strength variables have a negative relationship with the loan spread, but the relationships are not statistically significant. This is in contrast to the strong positive relationship between all of the individual environmental concerns variables and bank loan spreads documented in Table 4.

Table 6 Impact of the Individual Environmental Strengths on Bank Loan Spreads

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
benproduct	−0.2090 (−3.33)	−0.1617 (−2.40)						
polprevent			−0.0984 (−1.28)	−0.0597 (−0.69)				
cleanenergy					0.0606 (1.01)	−0.0725 (−1.08)		
envcomm							−0.0646 (−0.85)	−0.0015 (−0.02)
R^2	0.631	0.717	0.630	0.717	0.630	0.717	0.625	0.706
N	5,879	5,879	5,879	5,879	5,879	5,879	5,186	5,186
Firm-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
Loan-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Std. error clustering	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm

Notes. This table presents regression results relating bank loan spreads and individual environmental strengths of a firm. The dependent variable is the log of the all-in-drawn spread on the loan. The sample includes firms in the intersection of CRSP, Compustat, KLD, and Dealscan during 1992–2007. Variable definitions are given in Appendix B. Firm-level controls include *logasset*, *opincbefdep_a*, *lever*, *modzscore*, *unrated*, and *invgrade*. Loan-level controls include *loan purpose indicators*, *maturity*, *perfprice*, and *termloan*; and macro controls include *termspread* and *creditspread*. The *t*-statistics are given in parentheses below the estimates and are adjusted for firm-level clustering.

3.4. Robustness Tests

3.4.1. Expected Stock Returns. So far, I chose to present the results with each individual environmental concern and strength entering regressions separately so as to preserve the sample size. Given that some of the environmental profile variables are available only from 2000 onward, including all of the environmental concerns and strengths in one specification would restrict the sample period to only 2000–2007. However, the results remain qualitatively similar if I restrict the sample period to 2000–2007 and include all of the environmental strengths and concerns in one specification.

In all of the tables, I present results with and without industry fixed effects to document that industry is not always the main driving force of the relationship between expected stock returns and environmental concern and strength measures. The results are also robust to the inclusion of industry fixed effects using the Fama–French 48 industry classification system in lieu of the two-digit SIC code industry dummies. I present the results with year and industry fixed effects, with standard errors clustered at the firm level. I also check the robustness of the results to clustering the standard errors at the industry level. The results remain qualitatively and quantitatively similar.

I also run the regressions using the Fama–MacBeth approach by running separate annual regressions and considering the time series mean and standard error on the independent variables. The results do not materially change. I decided to present the pooled cross-sectional regressions using year and industry fixed effects instead of the Fama–MacBeth estimates, given the short time series availability of some of the key explanatory variables. For example, the climate change concerns variable is available only after 2000. In addition, the sample composition changed around 2001.

I use the past one month's stock return to control for any staleness in analysts' forecasts (Chava and Purnanandam 2010). The results remain similar if the previous three- or six-month cumulative stock return is used instead of the past one month's stock return. In the interest of space, I present the results only with the past one month's stock returns as one of the control variables.

3.4.2. Bank Loan Spreads. The relationship between the bank loan spread and environmental concerns and strengths remains quantitatively and qualitatively similar in a number of robustness tests. As in the ICC regressions, the results remain qualitatively similar if I restrict the sample period to 2000–2007 and include all of the strengths and concerns in one specification instead of including the individual concerns and strengths separately in each of the regressions.

First, as documented, the relationship is robust to the inclusion of industry fixed effects at the two-digit SIC level. In unreported tests, I find that the results are robust if I control for the industry factors at the Fama–French 48-industry level. In another robustness test, I include a dummy for whether a loan is collateralized or not. Information on whether a loan is collateralized or not is available only for approximately half of the sample and hence I do not include it in the main results. But in unreported tests I confirm that the inclusion of a dummy for whether a loan is secured or not does not materially impact the results. Another loan feature that I do not include in the main specifications is the loan size. Loan size is highly correlated with firm size. The inclusion of loan size, however, does not change the results significantly.

3.5. Is the Environmental Profile of a Firm Proxying for an Omitted Component of the Firm's Default Risk?

One concern with the results documented so far is that firms with more environmental concerns (strengths) have higher (lower) default risk (over and above the default risk proxied by the explanatory variables included in the loan spread specifications). In that case, lenders (and possibly stock investors) may simply be pricing the default risk of a firm and not necessarily its environmental concerns and strengths.

The ICC and loan spread regressions include many of the covariates that proxy for the firm's default risk, such as its size and leverage. Still, there may be a concern that environmental concerns and strengths are proxying for an omitted component of the default risk of the firm. To rule out this alternate explanation, I rely on a direct model of bankruptcy prediction used widely in the default risk literature. If environmental concerns and strengths are simply proxying for the default risk of the firm, then we should observe a higher (lower) number of defaults among firms with environmental concerns (strengths). To test this, I run a hazard model for bankruptcy prediction (Shumway 2001, Chava and Jarrow 2004, Chava et al. 2011) using individual environmental concerns and strengths as an additional covariate.

I estimate a Cox proportional hazards model with the dependent variable *bankruptcy* set to one if the firm has filed bankruptcy,[10] and zero otherwise. There is one observation per firm per year with the latest available accounting and market data. The covariates are from Shumway (2001) and are shown to

[10] Bankruptcies include both Chapter 7 and Chapter 11 bankruptcies during 1992–2007. Bankruptcy data are from Chava and Jarrow (2004) and Chava et al. (2011). The bankruptcy sample is comprehensive and includes the majority of bankruptcies among publicly listed firms during 1992–2007.

Table 7 Are Environmental Concerns and Strengths Proxying for an Omitted Component of a Firm's Default Risk? Evidence from Firm Bankruptcies

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
netconcerns	−0.3068										
	(−1.31)										
numconcerns		−0.1165									
		(−0.46)									
numstrength			0.4341								
			(1.76)								
climscore				−1.4313							
				(−2.73)							
hazardwaste					−0.5376						
					(−0.94)						
subemissions						0.3421					
						(0.60)					
climchange							−0.2387				
							(−0.28)				
benproduct								0.6108			
								(1.08)			
polprevent									0.4585		
									(0.70)		
cleanenergy										1.1633	
										(2.88)	
envcomm											1.0806
											(2.61)
N	20,149	20,149	20,149	15,106	20,149	20,149	15,106	20,149	20,149	20,149	16,984

Notes. This table presents the results of a Cox proportional hazards regression relating bankruptcy likelihood to the environmental concern and strength variables during 1992–2007. The regressions also include the following covariates (estimates not presented) from the Shumway (2001) model: netincome/total assets, total liabilities/total assets, log of market capitalization of the firm to the total market capitalization of all NYSE, AMEX, NASDAQ stocks, idiosyncratic volatility of firm's stock returns over the past 12 months, excess return of the stock over the market. Environmental variable definitions are given in Appendix B. The *t*-statistics are given in parentheses below the estimates and are adjusted for firm-level clustering.

have both in-sample and out-of-sample explanatory power to predict bankruptcy. They include net income to total assets (*nita*), total liabilities to total assets (*tlta*), equity volatility over the past 12 months (*sigma*), excess return over the market index (*exret*), and size relative to the market defined as the market capitalization of the firm divided by the total market capitalization of all AMEX/NYSE/NASDAQ stocks (*relsize*).

The results documented in Models 2, 5, 6, and 7 of Table 7 demonstrate that there is no significant relationship between environmental concerns and the likelihood of bankruptcy filing. If individual environmental concerns are simply proxying for the omitted default risk of the firm, then there should be a significant positive coefficient for the environmental concern variable. However, the coefficient of all the individual environmental concern variables are highly insignificant and in two out of three cases are in the opposite direction.

In a similar vein, it may be that firms with environmental strengths have a lower default risk, which explains the significantly lower spreads charged to firms that derive significant revenue from environmentally beneficial products (*benproduct*). The results in Model 8 show that this is not the case. Firms with *benproduct* environmental strength are not less likely to file bankruptcy. In fact, the coefficient is positive but not statistically significant. Interestingly, the results in Models 3, 10, and 11 show that firms with *polprevent* and *cleanenergy* are more likely to file for bankruptcy, but the results from Table 6 indicate that banks do not charge a higher spread on the loans to these firms.[11]

The results are qualitatively similar if I use a simple logistic model instead of the Cox proportional hazards model employed in the analysis. I chose to report Cox models because they take the time at risk into consideration and are statistically superior for bankruptcy prediction (Shumway 2001, Chava and Jarrow 2004). In unreported results, I estimated a model with frailty at the industry level (Chava et al. 2011). The results are qualitatively similar.

One concern with the bankruptcy models is that actual bankruptcies are rare.[12] It is plausible that these tests are weak powered and do not convincingly rule out the risk interpretation. To ameliorate this

[11] I remove Enron from the sample because it is clearly an accounting fraud case, but including it does not change the statistical significance of any of the results.

[12] The previous bankruptcy models are estimated using a sample of 93 bankruptcies.

Table 8 Are Environmental Concerns and Strengths Proxying for an Omitted Component of a Firm's Default Risk? Evidence from Covenant Violations

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
netconcerns	−0.0933										
	(−0.60)										
numconcerns		0.0309									
		(0.21)									
numstrength			0.2685								
			(1.41)								
climscore				−0.0602							
				(−0.17)							
hazardwaste					−0.1659						
					(−0.40)						
subemissions						0.4247					
						(1.23)					
climchange							0.2674				
							(0.77)				
benproduct								0.7192			
								(2.23)			
polprevent									0.0091		
									(0.01)		
cleanenergy										0.3212	
										(0.79)	
envcomm											0.0342
											(0.06)
N	12,596	12,596	12,596	10,112	12,596	12,596	10,112	12,596	12,596	12,596	11,107

Notes. This table presents the results of a Cox proportional hazards regression relating covenant violation likelihood to the environmental concern and strength variables during 1992–2007. The covenant violation data are from Nini et al. (2012) and contain records of covenant violations of all nonfinancial public firms from 1996 to 2007 from the SEC 10-Q and 10-K filings. The data are available at http://faculty.chicagobooth.edu/amir.sufi/data.html. After intersecting with KLD, CRSP, and Compustat, there are 234 covenant violations in my sample. The regressions also include the following covariates (estimates not presented) from the Shumway (2001) model: netincome/total assets, total liabilities/total assets, log of market capitalization of the firm to the total market capitalization of all NYSE, AMEX, NASDAQ stocks, idiosyncratic volatility of firm's stock returns over the past 12 months, excess return of the stock over the market. Environmental variable definitions are given in Appendix B. The t-statistics are given in parentheses below the estimates and are adjusted for firm-level clustering.

concern, I supplement the bankruptcy results with results from a Cox proportional hazards model using covenant violations in bank loans. Covenant violations are frequent and have a material impact on the firm (see Chava and Roberts 2008, Nini et al. 2012). I use the covenant violation data provided by Nini et al. (2012) that contain records of covenant violations of all nonfinancial public firms from 1996 to 2007 from the SEC 10-Q and 10-K filings.[13] After intersecting with KLD, CRSP, and Compustat, there are 234 covenant violations in my sample. I estimate a Cox proportional hazards model similar to the bankruptcy model with the main difference being that the event of interest is a covenant violation and not actual bankruptcy. The results are documented in Table 8 and are similar to the bankruptcy results in Table 7. These results highlight that there is no significant relationship between environmental concerns and the likelihood of covenant violations in bank loans.

Finally, I use credit rating downgrades as adverse events of interest as opposed to bankruptcies or covenant violations. There are 1,476 credit rating downgrades in our sample. Instead of a Cox proportional hazards model, here I use a stratified Cox model (SC model), which is an adaptation of the Cox proportional hazards model. The SC model uses stratification to control for a predictor that does not satisfy the proportional hazards assumption. More specifically, stratification allows the baseline hazard function to be different for different strata, defined here as the current credit rating. Chava et al. (2013) present more details of the sample construction and estimation of the SC model in the context of credit rating downgrades. The survival time at time t in the analysis is the number of quarters from now to the next rating change event, so it is denoted by $T - t$. The control variables are the one-quarter-lagged firm fundamentals (interest coverage dummies, log total assets, operating income to sales, long-term debt to assets, total debt to capitalization) based on the model of Chava et al. (2013). The results are presented in Table 9 and are in line with the results documented earlier using bankruptcies and covenant violations. These results indicate that there is no significant relationship between environmental concerns and the time to a

[13] The data are available at http://faculty.chicagobooth.edu/amir.sufi/data.html.

Table 9 Are Environmental Concerns and Strengths Proxying for an Omitted Component of a Firm's Default Risk? Evidence from Credit Rating Downgrades

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
netconcerns	−0.0022 (−0.03)										
numconcerns		−0.0025 (−0.03)									
numstrength			−0.0014 (−0.01)								
climscore				−0.0496 (−0.27)							
hazardwaste					−0.4168 (−1.55)						
subemissions						0.0015 (0.01)					
climchange							0.2030 (1.10)				
benproduct								0.2774 (0.88)			
polprevent									−0.5342 (−0.78)		
cleanenergy										0.1488 (0.66)	
envcomm											0.1058 (0.26)
N	13,615	13,615	13,615	12,390	13,615	13,615	12,390	13,615	13,615	13,615	13,214

Notes. This table presents the results of a stratified Cox proportional hazards analysis for credit rating downgrades using current credit rating as the strata. The survival time is the number of quarters until the next rating change event. Control variables consist of interest coverage dummies, log total assets, operating income to sales, long-term debt to assets, total debt to capitalization. The sample construction and model estimation is based on Chava et al. (2013). Environmental variable definitions are given in Appendix B. The t-statistics are given in parentheses below the estimates and are adjusted for firm-level clustering.

credit rating downgrade. The results using covenant violations and credit ratings ameliorate the concern that the bankruptcy results are weak powered.

But, it is difficult to conclusively rule out the alternate explanation that an omitted, possibly unobserved component of a firm's risk is driving the observed relationship between a firm's environmental profile and the cost of its debt and equity capital. A conservative interpretation of the bankruptcy results (Table 7), covenant violations (Table 8), and credit rating downgrades (Table 9) is that default risk is not exclusively driving the observed positive (negative) relationship between the environmental concerns (strengths) of a firm and its cost of equity and debt capital. Investors and lenders seem to be concerned about the environmental profile of a firm independent of its default risk.

4. Discussion: Why Does the Environmental Profile of a Firm Matter for Its Cost of Capital?

So far, I have documented that investors demand a higher expected return on the equity of firms with environmental concerns and, similarly, lenders charge a higher interest rate on the bank loans issued to firms with such environmental concerns. In this section, I address why stock investors and lenders could take the environmental profile of the firm into account.

4.1. Why Do Investors Expect Higher Stock Returns from Firms with Environmental Concerns?

The results documented in Tables 1, 3, and 5 show that there is a strong positive relationship between expected returns and environmental concern measures; however, there seems to be no statistically significant relationship between expected returns and environmental strengths (except clean energy without industry fixed effects). Why would investors demand a higher expected return from stocks of firms with environmental concerns? The natural possibility is that investors consider firms with environmental concerns riskier than firms without these environmental concerns. Investors may be pricing in the possibility of future regulation and the costs of compliance or costs associated with potential litigation for firms with environmental concerns. The regressions already include controls for important determinants of firm risk such as size and market-to-book ratio. In unreported tests,

Table 10 Impact of Environmental Concerns and Strengths on Institutional Ownership

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
			Panel A: Aggregate measures of environmental concerns and strengths					
netconcerns	−0.0114	−0.0059						
	(−3.16)	(−1.59)						
numconcerns			−0.0232	−0.0143				
			(−5.98)	(−3.31)				
numstrength					−0.0281	−0.0157		
					(−4.44)	(−2.66)		
climscore							−0.0251	−0.0119
							(−1.90)	(−1.20)
R^2	0.223	0.342	0.225	0.343	0.229	0.344	0.126	0.239
N	12,667	12,667	12,667	12,667	12,667	12,667	8,958	8,958
			Panel B: Individual environmental concerns					
hazardwaste	−0.0385	−0.0241						
	(−3.60)	(−2.16)						
subemissions			−0.0291	−0.0090				
			(−2.92)	(−0.94)				
climchange					−0.0932	−0.0392		
					(−6.53)	(−2.54)		
R^2	0.224	0.343	0.222	0.342	0.140	0.241		
N	12,667	12,667	12,667	12,667	8,958	8,958		
			Panel C: Individual environmental strengths					
benproduct	0.0072	0.0016						
	(0.49)	(0.12)						
polprevent			0.0013	−0.0238				
			(0.11)	(−1.97)				
cleanenergy					−0.0909	−0.0193		
					(−6.15)	(−1.60)		
envcomm							−0.0340	−0.0250
							(−2.16)	(−1.78)
R^2	0.221	0.342	0.221	0.342	0.233	0.342	0.151	0.269
N	12,667	12,667	12,667	12,667	12,667	12,667	10,332	10,332
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	Yes	No	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Std. error clustering	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm

Notes. This table presents regression results analyzing the impact of a firm's environmental profile on its institutional ownership. The dependent variable is the percentage of institutional ownership in the firm computed from Thomson 13-F data at the end of each calendar year. The sample period is 1992–2007. The control variables in the regression but whose coefficients are not presented in the table include log(market capitalization of the firm), log(market to book ratio of the firm), beta of the firms' stock computed from daily returns over the past one year, inverse of the stock price of the firm at the end of the fiscal year, mean monthly stock return over the past one year, volatility of daily stock returns over the past one year, indicator variable for whether the firm is a member of S&P 500, and indicator variable for whether the firm is listed in NASDAQ. Variable definitions are given in Appendix B. Robust *t*-statistics adjusted for firm-level clustering are presented in parentheses.

the inclusion of the firm's stock beta had no effect on the results. I also included proxies for default risk such as size, leverage, and volatilty (Shumway 2001, Chava and Jarrow 2004). In addition, in the previous section, I present evidence that alleviates the concern that a firm's environmental profile is proxying for an omitted component of its default risk.

Another distinct possibility is that, as publicized, socially responsible investors screen out stocks with environmental concerns. If a large number of investors use environmental screens to screen out stocks considered undesirable based on environmental concerns and hence do not invest in them, SRI can then impact the stock price and expected returns (Merton 1987, Heinkel et al. 2001). I present some evidence that is consistent with this hypothesis in Table 10.

4.1.1. Institutional Ownership and Number of Institutional Owners. To understand whether SRI is the driver behind the observed positive relationship between environmental concerns and expected stock returns, I analyze the relationship between total institutional ownership in a firm and its firm's environmental profile in Table 10. The key dependent variable is the total institutional ownership in the firm's stock, expressed as a percentage of the firm's shares outstanding. The data source for the institutional ownership is Thomson's 13-F data. I closely follow Hong and Kacperczyk (2009) for the regression specifications. In the interest of space, I present only the coefficients of individual environmental concerns and strengths, but all of the regressions include firm market capitalization, market to book ratio, stock beta, the inverse of stock price, the mean monthly return of the firm's stock over the past one year, volatility of the firm's stock return, a dummy for S&P 500 membership, and a dummy for whether the firm is listed on NASDAQ.

Panel A of Table 10 relates aggregate measures of environmental concerns with total institutional ownership. As before, I present results with and without industry fixed effects. The results show that firms with higher *netconcerns* and higher *numconcerns* have lower institutional ownership. These results are consistent with institutional investors screening stocks based on environmental concerns and consequently a higher cost of equity capital for the excluded stocks.[14] Interestingly, the coefficient estimates for *numstrength* and *climscore* reveal that institutional investors hold fewer stocks of firms with environmental strengths. The results in Panel C show that this is mainly due to the lower institutional holdings in firms with *cleanenergy* and *envcomm* environmental strengths.

In Panel B of Table 10, I consider the relationship between individual environmental concerns and total institutional ownership. The regression specification is the same as before. The results indicate that firms with environmental concerns, such as hazardous waste concerns, substantial emission concerns, and climate change concerns, have significantly lower institutional ownership compared to firms without such concerns. Interestingly, a firm that has concerns on all of these environmental dimensions has approximately 14%–15% lower institutional ownership, roughly in line with the percentage of dollars invested in SRI. The results in Panel C of Table 10 indicate that the percentage of institutional ownership is not higher for firms with environmental strengths. In fact, firms with clean energy and environmental communications strengths have significantly lower institutional ownership.

In unreported results, I consider the natural logarithm of the number of institutional owners as the key independent variable. The regression specification remains the same as in institutional ownership regressions. The results are also similar indicating that firms with environmental concerns such as hazardous waste and climate change concerns are held by significantly fewer institutional owners compared with firms that do not have these environmental concerns.

These institutional ownership and holdings results provide some positive evidence that exclusionary SRI can impact the expected stock returns of excluded firms, consistent with the results presented in Tables 1, 3, and 5. Although it is difficult to conclusively rule out the risk story, the observed lower institutional ownership for firms with environmental concerns suggests that an omitted risk factor may not be exclusively driving the higher ICC for firms with environmental concerns.

4.1.2. Growth in Socially Responsible Investing. Information on both the environmental profile of the firms and environmental sensitivity of investors has increased markedly over the last two decades. This is evident in the tremendous increase in the amount of money devoted to SRI, with a growth of 324% over the 1995–2007 time period and over 50 times in the last 20 years.[15] I analyze the impact of this secular shift in investor taste for SRI on the holding of norm constrained institutions and the cost of equity capital for affected firms.

I divide the sample period of 1992–2007 into two subsamples, the first from 1992 to 1999 and the second from 2000 to 2007. First, I consider holdings of norm constrained institutions such as pension funds (see Hong and Kacperczyk 2009) during these two sample periods. In Panel A of Table 11, I estimate regression specifications of norm constrained institutional holdings separately for the two sample periods. The controls and regression specifications are the same as in Table 10. Models 1, 3, 5, and 7 are for the time period 1992–1999 and Models 2, 4, 6, and 8 are for the time period 2000–2007. The results indicate that the norm constrained institutional holdings are not significantly related to the environmental concerns of the firm during the earlier part of the sample period (1992–1999). In contrast, in the latter part, during 2000–2007, norm constrained institutional holdings are significantly lower in firms with higher net environmental concerns, higher number of concerns and in firms with hazardous waste concerns. There is no meaningful relationship between norm constrained institutional holdings in firms with substantial emission concerns in both subsamples. These results are suggestive of the fact that the increased environmental sensitivity over time may have led to lower holdings by norm constrained institutions. These results have to be interpreted with caution since the categorization of institutions using Thomson data is not very reliable

[14] Kumar and Page (2011) provide evidence that sophisticated individuals deviate from established personal and social norms only when the perceived benefits are sufficiently large.

[15] The Social Investing Forum reports that $1 in every $8 ($3.07 trillion out of $25.1 trillion under management in the United States, as of 2010) is under SRI guidelines.

Table 11 Impact of Environmental Concerns on Norm Constrained Institutional Ownership and Expected Stock Returns

	1992–1999	2000–2007	1992–1999	2000–2007	1992–1999	2000–2007	1992–1999	2000–2007
	Panel A: Impact of environmental concerns on institutional ownership							
netconcerns	0.0004	−0.0036						
	(0.22)	(−2.41)						
numconcerns			0.0003	−0.0053				
			(0.12)	(−3.27)				
hazardwaste					−0.0025	−0.0091		
					(−0.43)	(−1.75)		
subemissions							0.0013	−0.0005
							(0.19)	(−0.12)
	Panel B: Impact of environmental concerns on expected stock returns							
netconcerns	0.1148	0.1939						
	(1.93)	(4.15)						
numconcerns			0.0043	0.2635				
			(0.06)	(5.14)				
hazardwaste					−0.0109	0.4859		
					(−0.07)	(3.28)		
subemissions							−0.0618	0.4766
							(−0.34)	(3.01)

Notes. This table considers the impact of environmental concerns on norm constrained institutional ownership (Panel A) and expected stock returns (Panel B) during two time periods 1992–1999 and 2000–2007. In each panel, Models 1, 3, 5, and 7 are for the time period 1992–1999 and Models 2, 4, 6, and 8 are for the time period 2000–2007. Panel A presents regression results analyzing the impact of a firm's environmental profile on its ownership of norm-constrained institutions (see Hong and Kacperczyk 2009). The dependent variable is the percentage of institutional ownership of norm-constrained institutions in the firm computed from Thomson 13-F data at the end of each calendar year. The control variables in the regression but whose coefficients are not presented in the table include log(market capitalization of the firm), log(market to book ratio of the firm), beta of the firms' stock computed from daily returns over the past one year, inverse of the stock price of the firm at the end of the fiscal year, mean monthly stock return over the past one year, volatility of daily stock returns over the past one year, indicator variable for whether the firm is a member of S&P 500, and indicator variable for whether the firm is listed in NASDAQ. Variable definitions are given in Appendix B. There are 4,157 observations during 1992–1999 time period and 8,998 observations during the 2000–2007 time period. Robust t-statistics adjusted for firm-level clustering are presented in parentheses. Panel B presents regression results analyzing the impact of environmental concerns on the expected stock returns. The dependent variable is the expected risk premium calculated as the difference between the ICC and one-year risk-free rate. The sample includes firms in the intersection of CRSP, Compustat, KLD, and I/B/E/S during 1992–2007. Appendix A contains the details of the ICC construction. Firm-level controls include *logta*, *mtb*, *lever*, *stdret*, and $ret_{t-1,t}$. Variable definitions are given in Appendix B. There are 4,147 observations during the 1992–1999 time period and 8,967 observations during the 2000–2007 time period. Robust t-statistics adjusted for firm-level clustering are presented in parentheses.

in the latter part of the sample and because the sample composition of KLD database has changed over time.

Next, I consider whether the secular increase in SRI investment over time had a significant impact on the cost of equity capital. Again, I estimate cost of equity capital regressions separately for the two subsamples, one from 1992–1999 and the second from 2000–2007. The regression specifications remain the same as in Table 3. The results are presented in Panel B of Table 11 and indicate that both economically and statistically, the relationship between expected stock returns and environmental concerns is much stronger during the latter time period than the early part of the sample. These results are consistent with lower holdings by norm constrained institutions in firms with environmental concerns during the latter part of the sample period. In conjunction, these results suggest that increased environmental sensitivity and a secular shift in taste for SRI as evidenced by the huge increase in SRI investment may have led to an increase in the expected return of stocks that are screened out on environmental concerns. These results are consistent with the investor preference for socially responsible investing affecting asset prices (Fama and French 2007) and such exclusionary socially responsible investment affecting the cost of capital of affected firms (Heinkel et al. 2001).

4.2. Why Do Lenders Charge Higher Interest Rates on Loans Issued to Firms with Environmental Concerns?

The results in Tables 2, 4, and 6 show that firms that have environmental concerns are charged a higher loan interest rate and firms with environmental strengths are charged a lower interest rate. Lenders seem to price all of the environmental concerns variables, including toxic emissions, hazardous waste, and climate change concerns. In contrast, lenders charge lower loan spreads only to firms that derive substantial revenues from environmentally beneficial products, but they do not seem to price the pollution prevention, clean energy, and environmental communication strengths of a firm.

Why would lenders care about the environmental concerns and strengths of a borrower? A nonexhaustive list of reasons why lenders may consider the environmental concerns of the borrower in their lending decisions include higher credit risk (through the potential for adverse impact of current or future regulation and increased scrutiny from regulators on the borrowers, litigation risk, and compliance costs for the borrowers due to environmental concerns);[16] and, more directly for the lender, reputation risk arising from lending to environmentally damaging firms; and finally, lender liability laws. The results presented in Table 7 should alleviate the concern that higher default risk is exclusively driving the observed relationship between bank loan spreads and the environmental profile of a firm.

4.2.1. Lender Liability Laws. Lenders are potentially liable for *environmental damage* caused by borrowers under the terms of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and its Superfund Amendments. Other relevant laws include the Resource Conservation and Recovery Act, the Clean Water Act, the Clean Air Act[17] and the Toxic Substance Control Act. Under these federal laws, current and past owners of contaminated property, or of businesses located on contaminated property, and those who dispose or transport hazardous substances are potentially liable for any clean up costs associated with the environmental damage. A lender could be potentially liable for clean up of hazardous waste spilled by a borrower if the lender is significantly involved in the borrowers decision making (e.g., see *United States v. Fleet Factors Corp.* and *United States v. Maryland Bank* & *Trust Co.*). CERCLA does provide a secured creditor exemption from liability for banks and other lenders that do not participate in the management of the property. Several court decisions had significantly limited the scope of the secured lender exemption under CERCLA and consequently Section 2502 of The Asset Conservation, Lender Liability, and Deposit Insurance Protection Act of 1996 clarified the liability of lenders,[18] but the banks may still be liable under the state environmental laws exposing the banks to risk of environmental litigation.

Recognizing the environmental risks faced by lenders, the Federal Deposit Insurance Corporation (FDIC) has issued guidelines to federally supervised depositary institutions to develop an *environmental risk assessment program*. FDIC suggests that as part of the institution's overall decision-making process, the environmental risk program should establish procedures for identifying and evaluating potential environmental concerns associated with lending practices and other actions relating to real property.[19]

4.2.2. Reputation Risk to Lenders. Another distinct possibility is that lenders will face a reputation risk as a result of lending to environmentally damaging projects. Lenders may partly be influenced by the bad publicity and social attitudes that are increasingly critical of the polluting firms. There are a number of anecdotes about how banks are becoming more environmentally sensitive.[20] Examples inlcude Bank of America's withdrawal from mountaintop removal, banks reluctance to financing tar sands and HSBC, as well as Rabobank curtailing their relationship with environmentally damaging firms (Zeller 2010).

Consequently, if a significant number of lenders concerned about social responsibility (similar to SRI), litigation risk, or reputation risk abstain from lending to firms with environmental concerns or price the litigation and reputation risk they may be exposed to, the potential effects on the affected firm's cost of debt capital would be similar to the increase in the cost of equity capital due to exclusionary green investing in the stock market (see Heinkel et al. 2001). However, the impact of a firm's environmental profile on its bank loan spreads could be muted if the bank

[16] For example, see Taillard (2010) and Hadlock and Sonti (2012) for the impact of asbestos litigation and Gormley and Matsa (2011) for corporate responses to liability risk arising from its workers exposure to newly identified carcinogens.

[17] For example, recently the EPA announced that it had reached preliminary findings that six greenhouse gasses endangered public welfare and that motor vehicles contribute to the environmental levels of four of these. The decision was required by the Clean Air Act, as interpreted by the U.S. Supreme Court.

[18] http://www.epa.gov/brownfields/laws/index.htm (last accessed May 6, 2014).

[19] FDIC (2006) further suggests that as part of environmental risk analysis, "Prior to making a loan, an initial environmental risk analysis needs to be conducted during the application process. An appropriate analysis may allow the institution to avoid loans that result in substantial losses or liability and provide the institution with information to minimize potential environmental liability on loans that are made. . . . In addition, the loan application might be designed to request relevant environmental information, such as the present and past uses of the property and the occurrence of any contacts by Federal, state, or local governmental agencies about environmental matters. It may be necessary for the loan officer or other representative of an institution to visit the site to evaluate whether there is obvious visual evidence of environmental concerns."

[20] Rainforest Action Network (RAN), an environmental action group, has persuaded supporters to cut up their Citigroup credit cards and mail them back to the company, and pressured college students not to sign up for the cards at all. Last winter, it even hung a large banner across from Citigroup's headquarters accusing it of "banking on" global warming and forest destruction. Citigroup opened a dialogue with the group prior to its 2003 annual meeting, where RAN was scheduled to introduce shareholder proposals related to environmental policies (Phillips and Pacelle 2003). On the same lines, RAN kept the pressure on banks financing mountaintop removal coal mining and tar sand exploration.

loan markets are not transparent and the identity of lenders of polluting firms cannot be easily identified or the lenders are not concerned about litigation risk stemming from lending to firms with environmental concerns.

4.2.3. Loan Syndicate Structure. In parallel with the institutional ownership analysis, I analyze whether fewer lenders participate in the loan syndicate of firms with environmental concerns. I present the results of the loan syndicate analysis in Table 12. The dependent variable is the natural logarithm of the number of lenders in the loan syndicate. The regressions include all of the control variables used in the loan spread regressions and year fixed effects. As before, I present results with and without industry fixed effects. I present results with summary environmental profile variables in Panel A of Table 12, with individual environmental concerns in Panel B and with individual environmental strengths variables in Panel C.

The results presented in Models 1 and 2 of Panel A of Table 12 show that firms with net environmental concerns have a significantly lower loan syndicate size. This seems to be mainly because firms with higher environmental concerns have a significantly lower syndicate size compared to firms without such environmental concerns (Models 3 and 4). The results are also economically significant. A firm with environmental concerns on all four dimensions considered has an approximately 18% lower syndicate size (or

Table 12 Impact of Environmental Profile on the Loan Syndicate Size

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Panel A: Aggregate measures of environmental concerns and strengths								
netconcerns	−0.0418	−0.0479						
	(−2.36)	(−2.43)						
numconcerns			−0.0441	−0.0492				
			(−2.23)	(−2.19)				
numstrength					0.0271	0.0538		
					(0.70)	(1.32)		
climscore							−0.0352	−0.0430
							(−0.84)	(−0.91)
R^2	0.283	0.414	0.283	0.414	0.282	0.413	0.334	0.413
N	5,879	5,879	5,879	5,879	5,879	5,879	4,602	4,602
Panel B: Individual environmental concerns								
hazardwaste	−0.0035	−0.0392						
	(−0.06)	(−0.66)						
subemissions			−0.1898	−0.1680				
			(−3.42)	(−2.86)				
climchange					−0.0548	−0.0539		
					(−0.95)	(−0.73)		
R^2	0.282	0.413	0.285	0.414	0.334	0.413		
N	5,879	5,879	5,879	5,879	4,602	4,602		
Panel C: Individual environmental strengths								
benproduct	0.1446	0.1290						
	(1.83)	(1.51)						
polprevent			0.0072	−0.0653				
			(0.08)	(−0.74)				
cleanenergy					−0.0302	0.1283		
					(−0.37)	(1.43)		
envcomm							−0.2322	−0.2388
							(−1.74)	(−1.81)
R^2	0.282	0.413	0.282	0.413	0.282	0.413	0.304	0.409
N	5,879	5,879	5,879	5,879	5,879	5,879	5,186	5,186
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	Yes	No	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Std. error clustering	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm

Notes. This table presents regression results analyzing the impact of a firm's environmental profile on the number of lenders participating in its loan syndicate. The dependent variable is the log(number of lenders in the loan syndicate). The sample includes firms in the intersection of CRSP, Compustat, KLD, and Dealscan during 1992–2007. Variable definitions are given in Appendix B. Control variables whose estimates are not presented include firm-level controls such as *log*(*totalassets*), *opincbefdep_a*, *lever*, *modzscore*, *unrated*, *invgrade*; loan-level controls such as *loan purpose indicators*, *maturity*, *perfprice*, and *termloan*; and macro controls such as *termspread* and *creditspread*. The *t*-statistics are given in parentheses below the estimates and are adjusted for firm-level clustering.

two fewer lenders) compared to a firm with no environmental concerns. Other models in Panel A show that there is no statistically significant relationship between the number of environmental strengths and the syndicate size. Lenders do not seem to be flocking to firms with environmental strengths. There is also no meaningful relationship between lending syndicate size and the climate score of a firm.

Panel B (Panel C) of Table 12 explores the relationship between individual environmental concerns (environmental strengths) and syndicate size. The coefficient estimate for all of the environmental concern variables is negative, but only *subemissions* has a statistically significant relationship with syndicate size. Fewer lenders (18% less, or two fewer lenders) participate in the loan syndicate of firms with substantial emissions concerns. Of the individual environmental strengths, only *benproduct* has a marginally significant relationship with lending syndicate size. The coefficient on *envcomm* is negative and marginally significant. Overall, these results are consistent with the bank loan pricing results presented earlier and suggest that some lenders could be avoiding lending to firms with environmental concerns due to either social responsibility considerations, lender liability laws, or reputation risk.

5. Conclusion

I provide evidence that the environmental profile of a firm has a significant effect on its cost of capital. In particular, both stock investors and private lenders, seem to take into account the environmental concerns of a firm, leading to a higher cost of equity and debt capital for the firm. Notably, firms with climate change concerns have a significantly higher cost of equity and debt capital, indicating that even though greenhouse gas emissions are not currently regulated, investors do seem to take these issues into consideration. On the other hand, in general, the cost of equity and debt capital are not lower for firms with environmental strengths. But lenders charge lower interest rates on bank loans to firms that derive significant revenue from environmentally beneficial products.

Further exploration reveals that the environmental profile of a firm is not simply proxying for some omitted firm-level default risk. It is a challenging task to conclusively rule out the risk story, but I provide evidence that the observed positive relationship between expected stock returns (spread on the bank loans) and a firm's environmental concerns is partly driven by socially responsible investors (environmentally sensitive lenders) screening out stocks with environmental concerns. The results suggest that exclusionary SRI and environmentally sensitive lending can significantly impact the cost of capital of affected firms.

Acknowledgments

This paper combines and supersedes two papers that were previously circulated, "Environmentally Responsible Lending" and "Socially Responsible Investing and Expected Stock Returns." For helpful comments and suggestions, the author thanks Guillermo Baquero, Rob Bauer, Matt Billett, Murillo Campello, Jeroen Derwall, Nadja Guenster, Edith Hotckiss, Kose John, Shane Johnson, Marcin Kacperczyk, Alok Kumar, Praveen Kumar, Scott Lee, Gregor Matvos, Micah Officer, Oguzan Karakas, Shagun Pant, Ralitsa Petkova, Amiyatosh Purnanandam, Michael Roberts, Phil Strahan, Jerome Taillard, Wei Yang, Vijay Yerramilli, Joe Hong Zou; participants at the 2010 European Financial Association Annual Meetings at Frankfurt, the 2010 International Conference on Corporate Finance and Financial Markets at City University of Hong Kong, and the 2011 Financial Intermediation Research Society program committee; seminar participants at Arizona State University, Bank of Canada, Boston College, Federal Reserve Bank of Atlanta, Georgia Institute of Technology, Michigan State University, University of Alabama, 2011 Spring Q Group Conference, the 2011 Center for Responsible Business Conference at the University of California, Berkeley, and the First Geneva Summit on Sustainable Finance organized by the University of Geneva (2013); and colleagues at the Center on Business Strategies for Sustainability at Georgia Tech.

Appendix A. Computing the ICC

I compute the ICC using the discounted cash flow model of equity valuation. I closely follow Gebhardt et al. (2001), Pastor et al. (2008), and Chava and Purnanandam (2010) to compute the ICC. Below, I reproduce the methodology from these papers for the sake of completeness. In this approach, the expected return on a stock is computed as the internal rate of return that equates the present value of free cash flows to the current price. The stock price $P_{i,t}$ of firm i at time t is given by

$$P_{i,t} = \sum_{k=1}^{k=\infty} \frac{E_t(FCFE_{i,t+k})}{(1+r_{i,e})^k}, \qquad \text{(A1)}$$

where $FCFE_{i,t+k}$ is the free cash flow to equity of firm i in year $t+k$, E_t is the expectation operator conditional on the information at time t, and $r_{i,e}$ is the ICC.

Equation (A1) models current stock price as the discounted sum of all future cash flows. I explicitly forecast cash flows for the next $T = 15$ years and capture the effect of subsequent cash flows using a terminal value calculation. I estimate the free cash flow to equity of firm i in year $t+k$ using

$$E_t(FCFE_{i,t+k}) = FE_{i,t+k} * (1 - b_{t+k}), \qquad \text{(A2)}$$

where $FE_{i,t+k}$ is the earnings estimate of firm i in year $t+k$ and b_{t+k} is its plowback rate. $FE_{i,t+k}$ is estimated using the earnings forecast available from the I/B/E/S database. I use one- and two-year-ahead consensus (median) forecasts as proxies for $FE_{i,t+1}$ and $FE_{i,t+2}$, respectively. I compute the earnings estimate for year $t+3$ by multiplying the year $t+2$ estimate by the consensus long-term growth forecast. I/B/E/S provides the long-term consensus growth forecast for most firms. In the case of missing data, I compute the growth rate using earnings forecasts for years $t+1$ and $t+2$.

I assign a value of 100% to firms with a growth rate above 100% and 2% to firms with a growth rate below 2% to avoid the outlier problems. I forecast earnings from year $t+4$ to $t+T+1$ by mean reverting the year $t+3$ earnings growth rate to a steady long-run value by year $t+T+2$. The steady state growth rate of a firm's earnings is assumed to be the GDP growth rate (g) as of the previous year. The growth rate for year $t+k$ is assumed to follow

$$g_{i,\,t+k} = g_{i,\,t+k-1} * \exp^{\ln(g/g_{i,\,t+3})/(T-1)}. \tag{A3}$$

Using these growth rates, I compute earnings as follows:

$$FE_{i,\,t+k} = FE_{i,\,t+k-1} * (1 + g_{i,\,t+k}). \tag{A4}$$

Next I compute the plowback rate (i.e., one minus the payout ratio) from the most recent fiscal year data. The payout is defined as the sum of dividends (DVC) and share repurchases (PRSTKC) minus any issuance of new equity (SSTK). I get the payout ratio by dividing this number by net income (IB) if it is positive. If I am unable to compute the plowback ratio based on this method, then I set it to the industry (two-digit SIC code) median payout ratio. If the payout ratio of a firm is above one or below −0.5, I set it to the industry median payout ratio as well. I use the plowback ratio computed using the above procedure for the first year of estimation and mean revert it to a steady state value by year $t+T+1$. The steady state formula assumes that the product of the return on new investments ROI and the plowback rate are equal to the growth rate in earnings in steady state (i.e., $g = ROI * b$ in steady state). I set ROI for new investments to r_e under the assumption that competition drives returns on new investments to the cost of equity. With these assumptions, the plowback rate for year $t+k$ ($k = 2, 3, \ldots, T$) is given by the following:

$$b_{i,\,t+k} = b_{i,\,t+k-1} - \frac{b_{i,\,t+1} - b_i}{T}, \tag{A5}$$

$$b_i = \frac{g}{r_{i,\,e}}. \tag{A6}$$

I compute terminal value as the following perpetuity: $TV_{i,\,t+T} = (FE_{i,\,t+T+1})/r_{i,\,e}$. Collecting all of the terms, I get the following equation that I solve for $r_{i,\,e}$ to get the ICC:

$$P_{i,\,t} = \sum_{k=1}^{k=T} \frac{FE_{i,\,t+k} * (1 - b_{i,\,t+k})}{(1 + r_{i,\,e})^k} + \frac{FE_{i,\,t+T+1}}{r_{i,\,e}(1 + r_{i,\,e}^T)}. \tag{A7}$$

Appendix B. Variable Definitions

B.1. Environmental Profile

Summary Measures of Environmental Concerns and Strengths

- *numconcerns* measures the total number of environmental concerns for the firm recorded in the KLD database.
- *numstrength* is the total number of environmental strengths for the firm recorded in the KLD database.
- *netconcerns* is a net measure of environmental concerns and is constructed as *numconcerns-numstrength*.
- *climscore* is constructed as the difference of climate change concerns (*climchange*) and clean energy strength (*cleanenergy*).

Individual Environmental Concerns Variables

- *hazardwaste* is a dummy variable that is coded as one if the company's liabilities for hazardous waste sites exceed $50 million, or if the company has recently paid substantial fines or civil penalties for waste management violations.
- *subemissions* is coded as one if the company's legal emissions of toxic chemicals (as defined by and reported to the EPA) from individual plants into the air and water are among the highest of the companies followed by KLD.
- *climchange* is a dummy variable that takes the value of one if the company derives substantial revenues from the sale of coal or oil and its derivative fuel products, or if the company derives substantial revenues indirectly from the combustion of coal or oil and its derivative fuel products.

Individual Environmental Strength Variables

- *benproduct* is a dummy that takes the value of one if the company derives substantial revenues from innovative remediation products, environmental services, or products that promote the efficient use of energy, or it has developed innovative products with environmental benefits. But this does not include services with questionable environmental effects, such as landfills, incinerators, waste-to-energy plants, and deep injection wells.
- *polprevent* is coded as one if the company has notably strong pollution prevention programs including both emissions reductions and toxic-use reduction programs.
- *cleanenergy* is coded as one if the company has taken significant measures to reduce its impact on climate change and air pollution through use of renewable energy and clean fuels or through energy efficiency or if the company has demonstrated a commitment to promoting climate-friendly policies and practices outside its own operations.
- *envcomm* is a dummy variable that takes the value of one if the company is a signatory to the Ceres Principles, publishes a notably substantive environmental report, or has notably effective internal communications systems in place for environmental best practices.

B.2. Definitons of Variables Used in the ICC Analysis

- *logta* refers to the natural logarithm of total book assets of the firm in billions of U.S. dollars.
- *mtb* is the market-to-book ratio of the firm.
- *lever* measures the leverage of the firm constructed as the ratio of total debt (sum of long-term- and short-term-debt) scaled by the total assets of the firm.
- *stdret* is the standard deviation of firm's daily stock returns over the past year.
- $ret_{t-1,\,t}$ represents the firm's past one month stock return.

B.3. Definitions of Variables Used in the Bank Loan Spread Analysis

Loan-Level Variables

- *aisd* is the all-in-drawn spread on the bank loan measured over the LIBOR.
- *loansize* is the amount of the loan in millions of U.S. dollars.
- *loanmat* indicates the maturity of the loan in months.
- *perfprice* is a dummy variable that takes the value of one if the loan has a performance pricing feature and zero otherwise.
- *termloan* is a dummy variable that takes the value of one if the loan is a term loan and zero otherwise.

Macro Variables

• *termspread* is constructed as the difference in yields between ten-year and one-year Treasury notes

• *creditspread* is the difference in yields between BAA and AAA corporate bonds.

Firm Characteristics

• *assets* refers to the total book assets of the firm in billions of U.S. dollars in the month before the loan.

• *logasset* refers to the natural logarithm of total book assets of the firm in billions of U.S. dollars.

• *opincbefdep_a* is the ratio of operating income before depreciation to the total assets of the firm.

• *lever* measures the leverage of the firm constructed as the ratio of total debt (sum of long-term and short-term debt) scaled by the total assets of the firm.

• *modzscore* is the modified *z*-score based on Graham et al. (1998).

• *unrated* is a dummy variable that takes the value of one if the firm does not have a public debt rating and zero otherwise.

• *invgrade* is a dummy variable that takes the value of one if the firm has public debt rated investment grade from Standard & Poor's and zero otherwise.

References

Acharya VV, Almeida H, Campello M (2013) Aggregate risk and the choice between cash and lines of credit. *J. Finance* 68: 2059–2116.

Bauer R, Hann D (2010) Corporate environmental management and credit risk. Working paper, Maastricht University, Maastricht, The Netherlands.

Bradley M, Roberts M (2003) The structure and pricing of corporate debt covenants. Working paper, Duke University, Durham, NC.

Brammer S, Brooks C, Pavelin S (2006) Corporate social performance and stock returns: UK evidence from disaggregate measures. *Financial Management* 35:97–116.

Carbon Principles, The (2008) Leading Wall Street banks establish the Carbon Principles. Press release, February 4, 2008, http://www.carbonprinciples.org/documents/Carbon%20Principles%20Press%20Release%20Final.pdf.

Chava S, Jarrow R (2004) Bankruptcy prediction with industry effects. *Rev. Finance* 8(4):537–569.

Chava S, Purnanandam A (2010) Is default risk negatively related to stock returns? *Rev. Financial Stud.* 23:2523–2559.

Chava S, Roberts M (2008) How does financing impact investment? *J. Finance* 63(5):2085–2121.

Chava S, Ganduri R, Ornthanalai C (2013) Are credit ratings still relevant? Working paper, Georgia Institute of Technology, Atlanta.

Chava S, Livdan D, Purnanandam A (2009) Do shareholder rights affect the cost of bank loans? *Rev. Financial Stud.* 22:2973–3004.

Chava S, Stefanescu C, Turnbull S (2011) Modeling the loss distribution. *Management Sci.* 57:1267–1287.

Cogan D (2008) Corporate Governance and Climate Change: The Banking Sector, Report, Ceres.

Derwall J, Verwijmeren P (2007) Corporate social responsibility and the cost of equity capital. Working paper, Rotterdam School of Management, Erasmus University, Rotterdam, The Netherlands.

El Ghoul S, Guedhami O, Kwok CCY, Mishra DR (2011) Does corporate social responsibility affect the cost of capital? *J. Banking Finance* 35:2388–2406.

Fama E, French K (2007) Disagreement, tastes and asset prices. *J. Financial Econom.* 83:667–689.

Federal Deposit Insurance Corporation (FDIC) (2006) Guidelines for an environmental risk program. http://www.fdic.gov/news/news/financial/2006/fil06098a.pdf.

Fernando C, Sharfman M, Uysal V (2010) Does greenness matter? The effect of corporate environmental performance on ownership structure, analyst coverage and firm value. Working paper, University of Oklahoma, Norman.

Fisher-Vanden K, Thorburn KS (2011) Voluntary corporate environmental initiatives and shareholder wealth. *J. Environment. Econom. Management* 62:430–445.

Gebhardt WR, Lee CMC, Swaminathan B (2001) Toward an implied cost of capital. *J. Accounting Res.* 39:135–176.

Gillan S, Hartzell J, Koch A, Starks L (2010) Firms environmental, social and governance (ESG) choices, performance and managerial motivation. Working paper, University of Texas at Austin, Austin.

Gollier C, Pouget S (2009) Shareholder activism and socially responsible investors: Equilibrium changes in asset prices and corporate behavior. Working paper, Toulouse School of Economics, Toulouse, France.

Gormley TA, Matsa DA (2011) Growing out of trouble? Corporate responses to liability risk. *Rev. Financial Stud.*, ePub ahead of print April 11, http://rfs.oxfordjournals.org/content/early/2011/04/11/rfs.hhr011.

Goss A, Roberts G (2011) The impact of corporate social responsibility on the cost of bank loans. *J. Banking Finance* 35: 1794–1810.

Hadlock CJ, Sonti R (2012) Financial strength and product market competition: Evidence from asbestos litigation. *J. Financial Quant. Anal.* 47:179–211.

Heinkel R, Kraus A, Zechner J (2001) The impact of green investment on corporate behavior. *J. Financial Quant. Anal.* 36: 431–449.

Holladay S (2010) Abate or abscond: Polluter's response to environmental regulation. Working paper, New York Univesity, New York.

Hong H, Kacperczyk M (2009) The price of sin: The effects of social norms on markets. *J. Financial Econom.* 93:15–36.

Houston JF, James C (1996) Bank information monopolies and mix of private and public debt claims. *J. Finance* 51:1863–1889.

Jiang D, Kumar A, Law K (2010) Do political preferences of equity analysts affect earnings forecasts and market prices? Working paper, University of Miami, Coral Gables, FL.

Kempf A, Osthoff P (2007) The effect of socially responsible investing on portfolio performance. *Eur. Financial Management* 13:908–922.

Kumar A (2010) Self-selection and the forecasting abilities of female equity analysts. *J. Accounting Res.* 48:393–435.

Kumar A, Page J (2011) Deviations from norms and informed trading. Working paper, University of Miami, Coral Gables, FL.

Landier A, Nair VB (2009) *Investing for Change*: *Profit from Sustainable Investment* (Oxford University Press Cary, NC).

Merton R (1987) A simple model of capital market equilibrium with incomplete information. *J. Finance* 42:483–510.

Nini G, Smith D, Sufi A (2012) Creditor control rights, corporate governance, and firm value. *Rev. Financial Stud.* 25(6): 1713–1761.

Pastor L, Sinha M, Swaminathan B (2008) Estimating the intertemporal risk-return tradeoff using the implied cost of capital. *J. Finance* 63:2859–2897.

Phillips MM, Pacelle M (2003) Banks accept 'equator principles.' *Wall Street Journal* (June 3), http://online.wsj.com/article/SB105467249622739000.html.

Sharfman M, Fernando C (2008) Environmental risk management and the cost of capital. *Strategic Management J.* 29:569–592.

Shumway T (2001) Forecasting bankruptcy more accurately: A simple hazard model. *J. Bus.* 74:101–124.

Statman M, Glushkov D (2008) The wages of social responsibility. Working paper, Santa Clara University, Santa Clara, CA.

Taillard J (2010) Thriving in the midst of financial distress? An analysis of firms exposed to asbestos litigation. Working paper, Boston College, Chestnut Hill, MA.

Tang Y, Wu JG, Zhang L (2013) Do anomalies exist ex ante? *Rev. Finance*, ePub ahead of print July 19, http://rof.oxfordjournals.org/content/early/2013/07/19/rof.rft026.abstract.

Zeller T Jr (2010) Banks grow wary of environmental risks. *New York Times* (August 30), http://www.nytimes.com/2010/08/31/business/energy-environment/31coal.html?_r=0.

Annex 538

N. Laframboise & S. Acevedo, “Man versus Mother Nature”, *Finance & Development,* 2014, pp. 44-47

MAN versus Mother Nature

Nicole Laframboise and Sebastian Acevedo

In the battle against natural disasters, forward-thinking macroeconomic policy can help countries prepare for and mitigate the eventual blow

IMAGES of destruction and grief following Typhoon Haiyan, which hit the Philippines in November 2013, are still fresh in our minds. They summon up similar scenes of devastation following the great south Asian tsunami of 2004 and Hurricane Katrina, which hit the United States in 2005. And the damages are not limited to immediate effects.

The New York Times ran a heartbreaking front-page story in November 2013, describing the plight of a young man in the Philippines who sustained a simple leg fracture after Typhoon Haiyan (Bradsher, 2013). He lay on a gurney in a makeshift hospital, surrounded by his children, for five days awaiting treatment, only to die from an infection.

Not surprisingly, disasters have long-lasting psychological consequences. In addition to the immediate direct human cost, natural disasters often exacerbate poverty and undermine social welfare. Developing economies—and their most vulnerable populations—are especially at risk.

Are there more natural disasters today and are they more severe? Or are we simply better informed thanks to modern real-time, round-the-clock media coverage? What about our response? Have we figured out—with technology and sophisticated communications—how to prepare and respond in a way that saves lives and limits economic damage?

Over the past 50 years, the frequency of natural disasters has indeed increased (see Chart 1). Reporting of disasters has improved dramatically, but there has also been a documented rise in the number and intensity of climatic disasters and more people and physical assets are concentrated in at-risk areas. Interestingly, in the past decade the number of reported disasters dipped, but the number of people affected and the related costs continued to rise.

The poor more at risk

Natural disasters are more common and affect more people in developing economies (all low- and middle-income countries as defined by the World Bank) than elsewhere

(Laframboise and Loko, 2012) (see Chart 2). Since the 1960s, about 99 percent of the people affected by natural disasters lived in developing economies (87 percent middle income, 12 percent low income), and 97 percent of all disaster-related deaths occurred there (64 percent middle income, 32 percent low income). Weighted by land area and population, small island states suffer the highest frequency of natural disasters. In the eastern Caribbean, a large natural disaster with damage equivalent to more than 2 percent of GDP can be expected every two to three years.

The most vulnerable members of society are the major victims of natural disasters.

Advanced economies are better equipped to absorb the cost of disasters because they have recourse to private insurance, higher domestic savings, and market financing. They also allocate more resources to reducing vulnerabilities—for example, by developing and enforcing building codes.

The dollar value of disaster damage is much larger in advanced economies because of the amount and concentration of capital, but as a percentage of national wealth and output, the damage is usually much greater in developing economies. For example, the direct costs of the large earthquake in Japan in 2011 were estimated at about 3.6 percent of GDP; in Haiti the direct cost of the 2010 earthquake far exceeded total GDP that year.

People in developing economies are more likely to live in high-risk areas, and those countries tend to have a weak infrastructure. Developing economies rely more on sectors such as agriculture and tourism that depend on the weather. Moreover, their economic sectors are more interconnected—which makes these countries' economies more vulnerable to shocks in other sectors, including through infrastructure and cross-sector-ownership linkages. Yet they lack adequate emergency coping mechanisms.

The most vulnerable members of society, both in high- and low-income countries, are the major victims of natural disasters. They have little, if any, savings to fund current consumption, and divesting any limited capital stock, such as livestock, lowers their productive capacity and lifetime earnings. They have limited labor skills and opportunity for mobility, and indirect effects such as inflation hurt them disproportionately. (Inflation often rises after a disaster, when shortages of essential goods and services generate demand pressure.) These all add up to permanent welfare losses.

Economic toll

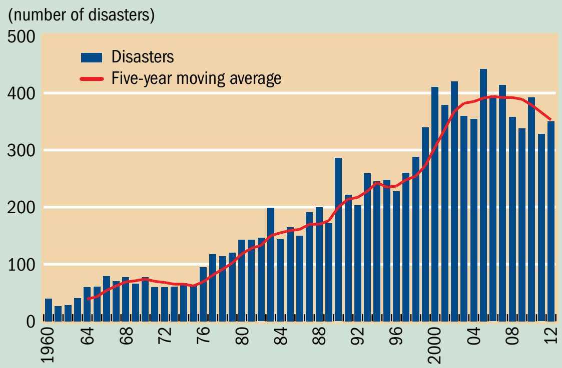
In the short term, economic output shrinks and the fiscal deficit worsens after a disaster. Countries' export potential suffers as well, which leads to larger deficits in trade and services with the rest of the world. The impact can be alleviated by foreign aid and investment, but after large disasters the growth and income effects usually persist. A country's growth drops by an average 0.7 percent in the first year after a disaster, with a cumulative output loss three years after the disaster of about 1.5 percent over and above the immediate direct losses. Per capita real GDP falls by about 0.6 percent on average and by 1 percent in low-income countries. Droughts have the broadest impact, except in small island states (for example, in the Caribbean; see box), where hurricanes are the most damaging.

After a major disaster, policymakers must decide whether to finance emergency spending by reducing or diverting existing spending or by borrowing. If the shock is deemed temporary—that is, physical recovery will take less than a year—it makes sense to borrow to support the domestic economy and offset the adverse effects of the shocks. This also helps maintain the incomes of those hardest hit and support the most vulnerable. If the effects of a disaster are long lasting, the economy must slowly adjust to a new equilib-

Chart 1

Calamity strikes

The frequency of natural disasters across the globe has increased steadily since 1960, dipping only in the past decade.

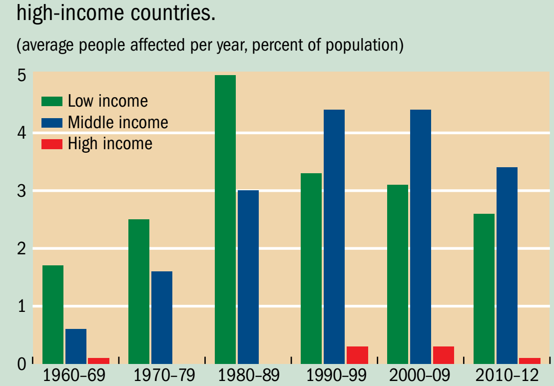


Sources: EM-DAT International Disaster Database; and IMF staff calculations.

Chart 2

Hardest hit

Disasters affect more people in developing countries than in high-income countries.



Sources: EM-DAT International Disaster Database; and authors' calculations.

Disaster impact in the Caribbean

The Caribbean region is one of the most disaster-prone areas in the world. In terms of disasters per capita and disasters per square kilometer, Caribbean countries are ranked among the top 50 riskiest places in the world (Rasmussen, 2006). More than 400 disasters afflicted the region between 1950 and 2012, including 267 tropical cyclones (usually hurricanes) and 113 floods. On average there is a 14 percent probability that a Caribbean country will be hit by a tropical storm in any given year, and in most countries the probability exceeds 10 percent.

The effect of natural disasters in the Caribbean on growth and debt are sizable. Strobl (2012) finds that the average hurricane reduces a country's output by nearly 1 percent; Acevedo (2013) finds similar results for severe storms and floods, and a smaller impact from moderate storms (0.5 percent). Growth typically follows a standard recovery path: activity rebounds shortly after a disaster thanks to rehabilitation and reconstruction. But this rebound is usually short lived and smaller than the initial impact, with a negative cumulative effect on GDP.

The impact on debt is even more dramatic. In the Eastern Caribbean Currency Union, the debt-to-GDP ratio rises by almost 5 percentage points on average the year a storm strikes (Acevedo, 2013). Viewed more broadly, however, Caribbean floods increase debt but storms do not. In part, this is because hurricanes attract more global media coverage, which drives aid and debt relief (Eisensee and Strömberg, 2007), whereas floods' impact is more local.

rium, and the government must smooth the transition and preserve macroeconomic stability.

In small island states and low-income countries, natural disasters often drive up public debt. Even with external assistance and remittance flows, public debt tends to rise. In the eastern Caribbean, this disaster-related increase has been significant. Take for example Hurricane Ivan, which hit Grenada in 2004. Ivan killed 39 people, displaced 60,000, and caused damages estimated at $890 million (150 percent of GDP). Output collapsed and the debt-to-GDP ratio rose by 15 percentage points in just one year, to 95 percent. Grenada underwent a debt restructuring in 2005 and continues to struggle with high debt today.

The impact of natural disasters depends on many things, including the size and structure of the economy, the concentration of people in high-risk areas, per capita income, and financial system development. Recent studies find that higher skills, better institutions (for example, local governments, health services, police, rule of law), more openness to trade, and higher government spending help lower the economic costs of a natural disaster (Noy, 2009). Better institutions and a better-educated population help ensure a capable and efficient disaster response, good allocation of foreign aid, and proper enforcement of such structural measures as building codes and zoning laws, which helps reduce damages when they hit. In addition, countries with healthy foreign exchange reserves and constraints on capital outflows can better withstand the capital flight that often follows a natural disaster.

Countries with deeper financial systems—that is, where more people have bank accounts and more households and businesses have bank loans—suffer less after a disaster. Countries with well-developed financial systems generally run up fiscal deficits but lose less in output. Deeper credit markets provide quicker access to local financing to fund recovery, minimizing the need for foreign borrowing, which can take longer to access or even be completely out of reach. Countries with deep financial systems *and* high insurance coverage fare the best, because the risk is transferred to outsiders (even in the case of local insurers through reinsurance policies), so investment and reconstruction place little or no extra fiscal burden on the state. Two large earthquakes in New Zealand in 2010 and 2011, for example, caused major damage—estimated at 10 percent of GDP—but insurance coverage (6 percent of GDP) transferred much of the cost of rehabilitation abroad. Activity did not contract, and growth in fact rose subsequently with reconstruction.

In general, the government policy response could be a combination of new financing and reserves drawdown, as well as macroeconomic adjustment in the form of current spending cuts or higher taxes. The IMF contributes at this stage, including as a catalyst for other lenders and by helping governments maintain macroeconomic stability and design the right policy response to lay the foundation for recovery.

Managing risk

While most natural disasters cannot be prevented, our research finds that more could be done to reduce their human and economic costs and minimize welfare losses. We found that there are steps the government can take before a disaster to mitigate the impact on people and output, particularly in countries very prone to disasters for geophysical or meteorological reasons. In such regions, a policy framework that explicitly takes into account the risks and costs of disasters would allow the government to better prepare for, and respond to, natural disaster shocks. Such preparation falls under the key pillars of risk assessment and reduction, self-insurance, and risk transfer (see table).

There are several obstacles to a more holistic, preventive approach to coping with disasters. First, many low-income countries lack the budget resources and technical and human capacity to prepare for disasters or to build levees or retrofit offices and homes to withstand storms. Countries with large debt overhangs are particularly constrained. These factors impede the development of mechanisms to reduce risk or self-insure—that is, either save for a rainy day or take out insurance for that day.

Second, it is difficult to allocate scarce resources that would otherwise be spent on much needed social spending or infrastructure, particularly when there is always the chance that the next "big one" may not hit for a while.

This is why efforts to assess the likelihood of disaster and key vulnerabilities should guide prevention and mitigation decisions.

Third, emergency aid and financing can be a strong but rational incentive for developing economies to underinvest in risk reduction. In fact, because such financing is offered at such low interest rates, it may not make sense to spend scarce resources before a disaster; the expense may not justify the expected return. Haiti, for example, received pledges of US$9.9 billion after the 2010 earthquake, 1.5 times the value of the country's nominal GDP. The country could not have paid for equivalent insurance coverage.

Finally, it is possible that countries are underestimating how much the probability of disasters has increased over time, particularly of climate-related disasters.

Should we be talking dollars and cents in the face of human tragedy? The first imperative of public policy should be to save lives, but efforts to reduce economic costs, which carry other human and social costs that can last for generations, are also important. When the economic costs are lessened resources are freed up for disaster preparedness, resilience, and mitigation, which can save lives in the future. Policymakers must ask whether, from the top down, disaster risk management has received sufficient attention in the decision-making process.

Planning ahead

Our research draws some basic and not-so-basic lessons from recent case studies. It finds that good macroeconomic policies before and after shocks make a difference. Some of the more basic lessons are that room in the budget for emergency spending helps crisis mitigation and resolution, insurance coverage and low public debt bolster government spending flexibility if reconstruction needs arise, and public investment in risk reduction pays off over time.

Less obviously, but still important, there is considerable room for improvement in government policy frameworks to better manage risk and mitigate economic and social costs (see table). In at-risk regions, policymakers should estimate the probability of shocks and identify local vulnerabilities. They can then integrate this information into plans for contingencies, investing in risk reduction, insurance, self-insurance, and disaster response.

Pillars of disaster risk management

Risk assessment	Risk reduction	Self-insurance	Risk transfer
Gather data, assess probability of natural disaster strike	Take measures to lower physical vulnerability, improve fiscal planning	Build savings, reserves	Boost insurance, reinsurance
Assess human and physical vulnerabilities	Embark on relocation, rebuilding, retrofitting, flood control, etc.	Build reserve fund, buffer stocks, etc.	Arrange for global insurance, pooled insurance (e.g., Caribbean Catastrophe Risk Insurance Facility)
Integrate information into fiscal framework, development plans	Establish building codes, alarms, emergency response, etc.	Establish rainy day funds, deepen financial system	Establish debt facility, catastrophe bonds, facilities with international financial institutions, etc.

Note: These pillars aim to guide policy formulation and ensure comprehensive planning, not to provide a specific sequence of steps.

Tax and spending policies need to be flexible, to allow rapid redeployment of spending when needed.

Coordination with foreign partners before disaster strikes could mobilize external assistance for risk reduction, which is likely to earn a higher return than emergency help after the fact.

Better cooperation between foreign partners after natural disasters is also sorely needed, particularly in low-income countries and in those with limited administrative capacity.

Insurance is the best way to reduce the real costs of natural disasters without raising taxes or cutting spending. Some innovative instruments have surfaced in recent years, but the international community could do more to pool resources and ideas to help vulnerable countries. The Caribbean Catastrophe Risk Insurance Facility (CCRIF) is one such example and has recently supported immediate relief to Caribbean countries. However, strained fiscal positions have left countries underinsured in the CCRIF and still exposed to shocks.

These are practical top-down policy suggestions for consideration during the calm between the inevitable storms. Most countries wait for the next disaster and then try to pick up the pieces quickly. Instead, policymakers and their foreign partners should integrate new and better ways to manage risk and reduce costs ahead of time. This would save lives, reduce suffering, and save money. And that would prevent unnecessary casualties—like the young man with the broken leg in the Philippines. ■

Nicole Laframboise is a Deputy Division Chief and Sebastian Acevedo is an Economist, both in the IMF's Western Hemisphere Department.

References:

Acevedo, Sebastian, 2013, "Debt, Growth and Natural Disasters: A Caribbean Trilogy" (unpublished; Washington: The George Washington University).

Bradsher, Keith, 2013, "Death after the Typhoon: It Was Preventable," The New York Times, *November 15.*

Eisensee, Thomas, and David Strömberg, 2007, "News Droughts, News Floods, and U.S. Disaster Relief," Quarterly Journal of Economics, *Vol. 122, No. 2, pp. 693–728.*

Laframboise, Nicole, and Boileau Loko, 2012, "Natural Disasters: Mitigating Impact, Managing Risks," IMF Working Paper 12/245 (Washington: International Monetary Fund).

Noy, Ilan, 2009, "The Macroeconomic Consequences of Disasters," Journal of Development Economics, *Vol. 88, No. 2, pp. 221–31.*

Rasmussen, Tobias, 2006, "Natural Disasters and Their Macroeconomic Implications," in The Caribbean: From Vulnerability to Sustained Growth, *ed. by Ratna Sahay, David Robinson, and Paul Cashin (Washington: International Monetary Fund), pp. 181–205.*

Strobl, Eric, 2012, "The Economic Growth Impact of Natural Disasters in Developing Countries: Evidence from Hurricane Strikes in the Central American and Caribbean Regions," Journal of Development Economics, *Vol. 97, No. 1, pp. 130–41.*

Annex 539

L. A. Nurse et al., *Small Islands*, in CLIMATE CHANGE 2014 – IMPACTS, ADAPTATION AND VULNERABILITY: PART B: REGIONAL ASPECTS: WORKING GROUP II CONTRIBUTION TO THE IPCC FIFTH ASSESSMENT REPORT, ed. V. R. Barros et al. (Cambridge University Press 2014), pp. 1613-1654

29

Small Islands

Coordinating Lead Authors:
Leonard A. Nurse (Barbados), Roger F. McLean (Australia)

Lead Authors:
John Agard (Trinidad and Tobago), Lino Pascal Briguglio (Malta), Virginie Duvat-Magnan (France), Netatua Pelesikoti (Samoa), Emma Tompkins (UK), Arthur Webb (Fiji)

Contributing Authors:
John Campbell (New Zealand), Dave Chadee (Trinidad and Tobago), Shobha Maharaj (Trinidad and Tobago), Veronique Morin (Canada), Geert Jan van Oldenborgh (Netherlands), Rolph Payet (Seychelles), Daniel Scott (Canada)

Review Editors:
Thomas Spencer (UK), Kazuya Yasuhara (Japan)

Volunteer Chapter Scientist:
Veronique Morin (Canada)

This chapter should be cited as:

Nurse, L.A., R.F. McLean, J. Agard, L.P. Briguglio, V. Duvat-Magnan, N. Pelesikoti, E. Tompkins, and A. Webb, 2014: Small islands. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1613-1654.

Table of Contents

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Frequently Asked Questions

Executive Summary

Current and future climate-related drivers of risk for small islands during the 21st century include sea level rise (SLR), tropical and extratropical cyclones, increasing air and sea surface temperatures, and changing rainfall patterns (*high confidence*; *robust evidence*, *high agreement*). {WGI AR5 Chapter 14; Table 29-1} Current impacts associated with these changes confirm findings reported on small islands from the Fourth Assessment Report (AR4) and previous IPCC assessments. The future risks associated with these drivers include loss of adaptive capacity {29.6.2.1, 29.6.2.3} and ecosystem services critical to lives and livelihoods in small islands. {29.3.1-3}

SLR poses one of the most widely recognized climate change threats to low-lying coastal areas on islands and atolls (*high confidence*; *robust evidence*, *high agreement*). {29.3.1} It is *virtually certain* that global mean SLR rates are accelerating. {WGI AR5 13.2.2.1} Projected increases to the year 2100 (RCP4.5: 0.35 m to 0.70 m) {WGI AR5 13.5.1; Table 29-1} superimposed on extreme sea level events (e.g., swell waves, storm surges, El Niño-Southern Oscillation) present severe sea flood and erosion risks for low-lying coastal areas and atoll islands (*high confidence*). Likewise, there is *high confidence* that wave over-wash of seawater will degrade fresh groundwater resources {29.3.2} and that sea surface temperature rise will result in increased coral bleaching and reef degradation. {29.3.1.2} Given the dependence of island communities on coral reef ecosystems for a range of services including coastal protection, subsistence fisheries, and tourism, there is *high confidence* that coral reef ecosystem degradation will negatively impact island communities and livelihoods.

Given the inherent physical characteristics of small islands, the AR5 reconfirms the high level of vulnerability of small islands to multiple stressors, both climate and non-climate (*high confidence*; *robust evidence*, *high agreement*). However, the distinction between observed and projected impacts of climate change is often not clear in the literature on small islands (*high agreement*). {29.3} There is evidence that this challenge can be partly overcome through improvements in baseline monitoring of island systems and downscaling of climate-model projections, which would heighten confidence in assessing recent and projected impacts. {WGI AR5 9.6; 29.3-4, 29.9}

Small islands do not have uniform climate change risk profiles (*high confidence*). Rather, their high diversity in both physical and human attributes and their response to climate-related drivers means that climate change impacts, vulnerability, and adaptation will be variable from one island region to another and between countries in the same region. {Figure 29-1; Table 29-3} In the past, this diversity in potential response has not always been adequately integrated in adaptation planning.

There is increasing recognition of the risks to small islands from climate-related processes originating well beyond the borders of an individual nation or island. Such transboundary processes already have a negative impact on small islands (*high confidence*; *robust evidence*, *medium agreement*). These include air-borne dust from the Sahara and Asia, distant-source ocean swells from mid to high latitudes, invasive plant and animal species, and the spread of aquatic pathogens. For island communities the risks associated with existing and future invasive species and human health challenges are projected to increase in a changing climate. {29.5.4}

Adaptation to climate change generates larger benefit to small islands when delivered in conjunction with other development activities, such as disaster risk reduction and community-based approaches to development (*medium confidence*). {29.6.4} Addressing the critical social, economic, and environmental issues of the day, raising awareness, and communicating future risks to local communities {29.6.3} will *likely* increase human and environmental resilience to the longer term impacts of climate change. {29.6.1, 29.6.2.3; Figure 29-5}

Adaptation and mitigation on small islands are not always trade-offs, but can be regarded as complementary components in the response to climate change (*medium confidence*). Examples of adaptation-mitigation interlinkages in small islands include energy supply and use, tourism infrastructure and activities, and functions and services associated with coastal wetlands. The alignment of these sectors for potential emission reductions, together with adaptation, offer co-benefits and opportunities in some small islands. {29.7.2, 29.8} Lessons learned from adaptation and mitigation experiences in one island may offer some guidance to other small island states, though there is *low confidence* in the success of wholesale transfer of adaptation and mitigation options when the local lenses through which they are viewed differ from one island state to the next, given the diverse cultural, socioeconomic, ecological, and political values. {29.6.2, 29.8}

The ability of small islands to undertake adaptation and mitigation programs, and their effectiveness, can be substantially strengthened through appropriate assistance from the international community (*medium confidence*). However, caution is needed to ensure such assistance is not driving the climate change agenda in small islands, as there is a risk that critical challenges confronting island governments and communities may not be addressed. Opportunities for effective adaptation can be found by, for example, empowering communities and optimizing the benefits of local practices that have proven to be efficacious through time, and working synergistically to progress development agendas. {29.6.2.3, 29.6.3, 29.8}

29.1. Introduction

It has long been recognized that greenhouse gas (GHG) emissions from small islands are negligible in relation to global emissions, but that the threats of climate change and sea level rise (SLR) to small islands are very real. Indeed, it has been suggested that the very existence of some atoll nations is threatened by rising sea levels associated with global warming. Although such scenarios are not applicable to all small island nations, there is no doubt that on the whole the impacts of climate change on small islands will have serious negative effects especially on socioeconomic conditions and biophysical resources—although impacts may be reduced through effective adaptation measures.

The small islands considered in this chapter are principally sovereign states and territories located within the tropics of the southern and western Pacific Ocean, central and western Indian Ocean, the Caribbean Sea, and the eastern Atlantic off the coast of West Africa, as well as in the more temperate Mediterranean Sea.

Although these small islands nations are by no means homogeneous politically, socially, or culturally, or in terms of physical size and character or economic development, there has been a tendency to generalize about the potential impacts on small islands and their adaptive capacity. In this chapter we attempt to strike a balance between identifying the differences between small islands and at the same time recognizing that small islands tend to share a number of common characteristics that have distinguished them as a particular group in international affairs. Also in this chapter we reiterate some of the frequently voiced and key concerns relating to climate change impacts, vulnerability, and adaptation while emphasizing a number of additional themes that have emerged in the literature on small islands since the IPCC Fourth Assessment Report (AR4). These include the relationship among climate change policy, activities, and development issues; externally generated transboundary impacts; and the implications of risk in relation to adaptation and the adaptive capacity of small island nations.

29.2. Major Conclusions from Previous Assessments

Small islands were not given a separate chapter in the IPCC First Assessment Report (FAR) in 1990 though they were discussed in the chapter on "World Oceans and Coastal Zones" (Tsyban et al., 1990). Two points were highlighted. First, a 30- to 50-cm SLR projected by 2050 would threaten low islands, and a 1-m rise by 2100 "would render some island countries uninhabitable" (Tegart et al., 1990, p. 4). Second, the costs of protection works to combat SLR would be extremely high for small island nations. Indeed, as a percentage of gross domestic product (GDP), the Maldives, Kiribati, Tuvalu, Tokelau, Anguilla, Turks and Caicos, Marshall Islands, and Seychelles were ranked among the 10 nations with the highest protection costs in relation to GDP (Tsyban et al., 1990). More than 20 years later these two points continue to be emphasized. For instance, although small islands represent only a fraction of total global damage projected to occur as a result of a SLR of 1.0 m by 2100 (*Special Report on Emission Scenarios* (SRES) A1 scenario) the actual damage costs for the small island states is enormous in relation to the size of their economies, with several small island nations being included in the group of 10 countries with the highest relative impact projected for 2100 (Anthoff et al., 2010).

The Second Assessment Report (SAR) in 1995 confirmed the vulnerable state of small islands, now included in a specific chapter titled "Coastal Zones and Small Islands" (Bijlsma et al., 1996). However, importantly, the SAR recognized that both vulnerability and impacts would be highly variable between small islands and that impacts were "likely to be greatest where local environments are already under stress as a result of human activities" (Bijlsma et al., 1996, p. 291). The report also summarized results from the application of a common methodology for vulnerability and adaptation analysis that gave new insights into the socioeconomic implications of SLR for small islands including: negative impacts on virtually all sectors including tourism, freshwater resources, fisheries and agriculture, human settlements, financial services, and human health; protection is likely to be very costly; and adaptation would involve a series of trade-offs. It also noted that major constraints to adaptation on small islands included lack of technology and human resource capacity, serious financial limitations, lack of cultural and social acceptability, and uncertain political and legal frameworks. Integrated coastal and island management was seen as a way of overcoming some of these constraints.

The Third Assessment Report (TAR) in 2001 included a specific chapter on "Small Island States." In confirming previously identified concerns of small island states two factors were highlighted, the first relating to sustainability, noting that "with limited resources and low adaptive capacity, these islands face the considerable challenge of meeting the social and economic needs of their populations in a manner that is sustainable" (Nurse et al., 2001, p. 845). The second noted that there were other issues faced by small island states, concluding that "for most small islands the reality of climate change is just one of many serious challenges with which they are confronted" (Nurse et al., 2001, p. 846). In the present chapter, both of these themes are raised again and assessed in light of recent findings.

Until the AR4 in 2007, SLR had dominated vulnerability and impact studies of small island states. Whilst a broader range of climate change drivers and geographical spread of islands was included in the "Small Islands" chapter, Mimura et al. (2007) prefaced their assessment by noting that the number of "independent scientific studies on climate change and small islands since the TAR" had been quite limited and in their view "the volume of literature in refereed international journals relating to small islands and climate change since publication of the TAR is rather less than that between the SAR in 1995 and TAR in 2001" (Mimura et al., 2007, p. 690).

Since AR4, the literature on small islands and climate change has increased substantially. A number of features distinguish the literature we review here from that included in earlier assessments. First, the literature appears more sophisticated and does not shirk from dealing with the complexity of small island vulnerability, impacts, and adaptation or the differences between islands and island states. Second, and related to the first, the literature is less one-dimensional, and deals with climate change in a multidimensional manner as just one of several stressors on small island nations. Third, the literature also critiques some aspects of climate change policy, notably in relation to critical present-day development and security needs of small islands (Section 29.3.3.1) as well as the possibility that some proposed adaptation measures may prove to be maladaptive (Section 29.8). Fourth, many initiatives have been identified in recent times that will reduce vulnerability and enhance resilience of small islands to ongoing global change including improving risk knowledge and island resource management while also strengthening socioeconomic systems and livelihoods (Hay, 2013).

29.3. Observed Impacts of Climate Change, Including Detection and Attribution

The distinction between observed impacts of climate change and projected impacts is often unclear in the small islands literature and discussions. Publications frequently deal with both aspects of impacts interchangeably, and use observed impacts from, for instance an extreme event, as an analogy to what may happen in the future as a result of climate change (e.g., Lo-Yat et al., 2011). The key climate and ocean drivers of change that impact small islands include variations in air and ocean temperatures; ocean chemistry; rainfall; wind strength and direction; sea levels and wave climate; and particularly the extremes such as tropical cyclones, drought, and distant storm swell events. All have varying impacts, dependent on the magnitude, frequency, and temporal and spatial extent of the event, as well as on the biophysical nature of the island (Figure 29-1) and its social, economic, and political setting.

29.3.1. Observed Impacts on Island Coasts and Marine Biophysical Systems

29.3.1.1. Sea Level Rise, Inundation, and Shoreline Change

SLR poses one of the most widely recognized climate change threats to low-lying coastal areas (Cazenave and Llovel, 2010; Nicholls and Cazenave, 2010; Church and White, 2011). This is particularly important in small islands where the majority of human communities and infrastructure is located in coastal zones with limited on-island relocation opportunities, especially on atoll islands (Woodroffe, 2008) (Figure 29-1). Over much of the 20th century, global mean sea level rose at a rate between 1.3 and 1.7 mm yr^{-1} and since 1993, at a rate between 2.8 and 3.6 mm yr^{-1} (WGI AR5 Table 13.1), and acceleration is detected in longer records since 1870 (Merrifield et al., 2009; Church and White, 2011; see also WGI AR5 Section 13.2.2.1). Rates of SLR, however, are not uniform across the globe and large regional differences have been detected including in the Indian Ocean and tropical Pacific, where in some parts rates have been significantly higher than the global average (Meyssignac et al., 2012; see also Section 5.3.2.2). In the tropical western Pacific, where a large number of small island communities exist, rates up to four times the global average (approximately 12 mm yr^{-1}) have been reported between 1993 and 2009. These are generally thought to describe short-term variations associated with natural cyclic climate phenomena such as El Niño-Southern Oscillation (ENSO), which has a strong modulating effect on sea level variability with lower/higher-than-average sea level during El Niño/La Niña events of the order of ±20 to 30 cm (Cazenave and Remy, 2011; Becker et al., 2012). Large interannual variability in sea level has also been demonstrated from the Indian Ocean (e.g., Chagos Archipelago; Dunne et al., 2012) while Palanisamy et al. (2012) found that over the last 60 years the mean rate of SLR in the Caribbean region was similar to the global average of approximately 1.8 mm yr^{-1}.

There are few long-term sea level records available for individual small island locations. Reported sea flooding and inundation is often associated with transient phenomena, such as storm waves and surges, deep ocean swell, and predicted astronomical tidal cycles (Vassie et al., 2004; Zahibo et al., 2007; Komar and Allan, 2008; Haigh et al., 2011). For example, high spring tide floods at Fongafale Island, Funafuti Atoll, Tuvalu, have been well publicized, and areas of the central portion of Fongafale are

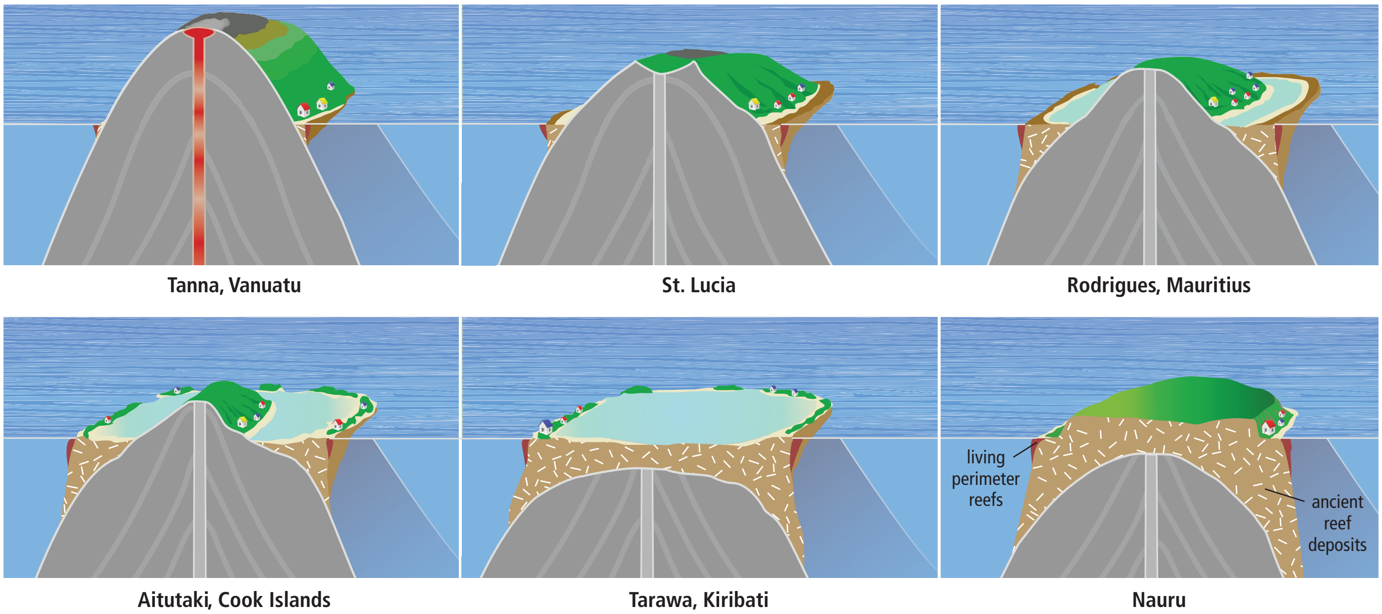


Figure 29-1 | Representative tropical island typologies. From top left: A young, active volcanic island (with altitudinal zonation) and limited living perimeter reefs (red zone at outer reef edge), through to an atoll (center bottom), and raised limestone island (bottom right) dominated by ancient reef deposits (brown + white fleck). Atolls have limited, low-lying land areas but well developed reef/lagoon systems. Islands composed of continental rocks are not included in this figure, but see Table 29-3.

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Frequently Asked Questions

FAQ 29.1 | Why is it difficult to detect and attribute changes on small islands to climate change?

In the last 2 or 3 decades many small islands have undergone substantial changes in human settlement patterns and in socioeconomic and environmental conditions. Those changes may have masked any clear evidence of the effects of climate change. For example, on many small islands coastal erosion has been widespread and has adversely affected important tourist facilities, settlements, utilities, and infrastructure. But specific case studies from islands in the Pacific, Indian, and Atlantic Oceans and the Caribbean have shown that human impacts play an important role in this erosion, as do episodic extreme events that have long been part of the natural cycle of events affecting small islands. So although coastal erosion is consistent with models of sea level rise resulting from climate change, determining just how much of this erosion might have been caused by climate change impacts is difficult. Given the range of natural processes and human activities that could impact the coasts of small islands in the future, without more and better empirical monitoring the role of climate change-related processes on small islands may continue to be difficult to identify and quantify.

already below high spring tide level. However, rates of relative SLR at Funafuti between 1950 and 2009 have been approximately three times higher than the global average (Becker et al., 2012), and saline flooding of internal low-lying areas occurs regularly and is expected to become more frequent and extensive over time (Yamano et al., 2007).

Documented cases of coastal inundation and erosion often cite additional circumstances such as vertical subsidence, engineering works, development activities, or beach mining as the causal process. Four examples can be cited. First, on the Torres Islands, Vanuatu communities have been displaced as a result of increasing inundation of low-lying settlement areas owing to a combination of tectonic subsidence and SLR (Ballu et al., 2011). Second, on Anjouan Island, Comores in the Indian Ocean, Sinane et al. (2010) found beach aggregate mining was a major contributing factor influencing rapid beach erosion. Third, the intrinsic exposure of rapidly expanding settlements and agriculture in the low-lying flood prone Rewa Delta, Fiji, is shown by Lata and Nunn (2012) to place populations in increasingly severe conditions of vulnerability to flooding and marine inundation. Fourth, Hoeke et al. (2013) describe a 2008 widespread inundation event that displaced some 63,000 people in Papua New Guinea and Solomon Islands alone. That event was caused primarily by remotely generated swell waves, and the severity of flooding was greatly increased by anomalously high regional sea levels linked with ENSO and ongoing SLR. Such examples serve to highlight that extreme events superimposed on a rising sea level baseline are the main drivers that threaten the habitability of low-lying islands as sea levels continue to rise.

Since the AR4 a number of empirical studies have documented historical changes in island shorelines. Historical shoreline position change over 20 to 60 years on 27 central Pacific atoll islands showed that total land area remained relatively stable in 43% of islands, while another 43% had increased in area, and the rest showed a net reduction in land area (Webb and Kench, 2010). Dynamic responses were also found in a 4-year study of 17 relatively pristine islands on two other central Pacific atolls in Kiribati by Rankey (2011), who concluded that SLR was not likely to be the main influencing factor in these shoreline changes. Similarly in French Polynesia, Yates et al. (2013) showed mixed shoreline change patterns over the last 40 to 50 years with examples of both erosion and accretion in the 47 atoll islands assessed. SLR did not appear to be the primary control on shoreline processes on these islands. On uninhabited Raine Island on the Great Barrier Reef, Dawson and Smithers (2010) also found that shoreline processes were dynamic but that island area and volume increased 6 and 4%, respectively, between 1967 and 2007. Overall, these studies of observed shoreline change on reef islands conclude that for rates of change experienced over recent decades, normal seasonal erosion and accretion processes appear to predominate over any long-term morphological trend or signal at this time. Ford's (2013) investigation of Wotje Atoll, Marshall Islands, also found shoreline variability between 1945 and 2010 but that overall accretion had been more prevalent than erosion up until 2004. From 2004 to the present, 17 out of 18 islands became net erosive, potentially corresponding to the high sea levels in the region over the last 10 years. On the high tropical islands of Kauai and Maui, Hawaii, Romine and Fletcher (2013) found shoreline change was highly variable over the last century but that recently chronic erosion predominated with over 70% of beaches now being erosive. Finally, it is important to note the majority of these studies warn that (1) past changes cannot be simply extrapolated to determine future shoreline responses; and (2) rising sea level will incrementally increase the rate and extent of erosion in the future.

In many locations changing patterns of human settlement and direct impacts on shoreline processes present immediate erosion challenges in populated islands and coastal zones (Yamano et al., 2007; Novelo-Casanova and Suarez, 2010; Storey and Hunter, 2010) and mask attribution to SLR. A study of Majuro atoll (Marshall Islands) found that erosion was widespread but attribution to SLR was obscured by pervasive anthropogenic impacts to the coastal system (Ford, 2012; see Section 5.4.4). Similarly a study of three islands in the Rosario Archipelago (Colombia) reported shoreline retreat over a 50- to 55-year period and found Grande, Rosario, and Tesoro Islands had lost 6.7, 8.2, and 48.7% of their land area, respectively. Erosion was largely attributed to poor management on densely settled Grande Island, while SLR and persistent

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

northeast winds enhanced erosion on uninhabited Rosario and Tesoro (Restrepo et al., 2012). Likewise, Cambers (2009) reported average beach erosion rates of 0.5 m yr^{-1} in eight Caribbean islands from 1985 to 2000. Although the study could not quantify the extent of attribution it noted that greater erosion rates were positively correlated with the number of hurricane events. Alternately, Etienne and Terry (2012) found a Category 4 tropical cyclone that passed within 30 km of Taveuni Island (Fiji) nourished shorelines with fresh coralline sediments despite localized storm damage. Although these studies contribute to improved understanding of island shoreline processes and change since AR4, the warning of increased vulnerability of small island shores and low-lying areas to inundation and erosion in response to SLR and other potential climate change stressors is not diminished.

29.3.1.2. Coastal Ecosystem Change on Small Islands: Coral Reefs and Coastal Wetlands

Coral reefs are an important resource in small tropical islands, and the well-being of many island communities is linked to their ongoing function and productivity. Reefs play a significant role in supplying sediment to island shores and in dissipating wave energy, thus reducing the potential foreshore erosion. They also provide habitat for a host of marine species on which many island communities are dependent for subsistence foods as well as underpinning beach and reef-based tourism and economic activity (Perch-Nielsen, 2010; Bell et al., 2011). The documented sensitivity of coral reef ecosystems to climate change is summarized elsewhere (see Chapter 5; Box CC-CR).

Increased coral bleaching and reduced reef calcification rates due to thermal stress and increasing carbon dioxide (CO_2) concentration are expected to affect the functioning and viability of living reef systems (Hoegh-Guldberg et al., 2007; Eakin et al., 2009). Some studies already implicate thermal stress in reduced coral calcification rates (Tanzil et al., 2009) and regional declines in calcification of corals that form reef framework (De'ath et al., 2009; Cantin et al., 2010). Unprecedented bleaching events have been recorded in the remote Phoenix Islands (Kiribati), with nearly 100% coral mortality in the lagoon and 62% mortality on the outer leeward slopes of the otherwise pristine reefs of Kanton Atoll during 2002–2003 (Alling et al., 2007). Similar patterns of mortality were observed in four other atolls in the Phoenix group and temperature-induced coral bleaching was also recorded in isolated Palmyra Atoll during the 2009 ENSO event (Williams et al., 2010). In 2005 extensive bleaching was recorded at 22 sites around Rodrigues Island in the western Indian Ocean, with up to 75% of the dominant species affected in some areas (Hardman et al., 2007). Studies of the severe 1998 El Niño bleaching event in the tropical Indian Ocean showed reefs in the Maldives, Seychelles, and Chagos Islands were among the most impacted (Cinner et al., 2012; Tkachenko, 2012). In 2005 a reef survey around Barbados following a Caribbean regional bleaching event revealed the most severe bleaching ever recorded, with approximately 70% of corals impacted (Oxenford et al., 2008). Globally, the incidence and implications of temperature-related coral bleaching in small islands is well documented, and combined with the effects of increasing ocean acidification these stressors could threaten the function and persistence of island coral reef ecosystems (see Chapter 5; Box CC-OA).

Island coral reefs have limited defenses against thermal stress and acidification. However, studies such as Cinner et al. (2012) and Tkachenko (2012) highlight that although recovery from bleaching is variable, some reefs show greater resilience than others. There is also some evidence to show that coral reef resilience is enhanced in the absence of other environmental stresses such as declining water quality. In Belize chronologies of growth rates in massive corals (*Montastraea faveolata*) over the past 75 to 150 years suggest that the bleaching event in 1998 was unprecedented and its severity appeared to stem from reduced thermal tolerance related to human coastal development (Carilli et al., 2010). Likewise a study over a 40-year period (1960s–2008) in the Grand Recif of Tulear, Madagascar, concluded that severe degradation of the reef was mostly ascribed to direct anthropogenic disturbance, despite an average 1°C increase in temperature over this period (Harris et al., 2010). Coral recovery following the 2004 bleaching event in the central Pacific atolls of Tarawa and Abaiang (Kiribati) was also noted to be improved in the absence of direct human impacts (Donner et al., 2010), and isolation of bleached reefs was shown by Gilmour et al. (2013) to be less inhibiting to reef recovery than direct human disturbance.

The loss of coral reef habitat has detrimental implications for coastal fisheries (Pratchett et al., 2009) in small islands where reef-based subsistence and tourism activities are often critical to the well-being and economies of islands (Bell et al., 2011). In Kimbe Bay, Papua New Guinea, 65% of coastal fish are dependent on living reefs at some stage in their life cycle and there is evidence that fish abundance declined following degradation of the reef (Jones et al., 2004). Even where coral reef recovery has followed bleaching, reef-associated species composition may not recover to its original state (Pratchett et al., 2009; Donner et al., 2010). Sea surface temperature (SST) anomaly events can be associated with a lag in the larval supply of coral reef fishes, as reported by Lo-Yat et al. (2011) between 1996 and 2000 at Rangiroa Atoll, French Polynesia. Higher temperatures have also been implicated in negatively affecting the spawning of adult reef species (Munday et al., 2009; Donelson et al., 2010).

Like coral reefs, mangroves and seagrass environments provide a range of ecosystem goods and services (Waycott et al., 2009; Polidoro et al., 2010) and both habitats play a significant role in the well-being of small island communities. Mangroves in particular serve a host of commercial and subsistence uses as well as providing natural coastal protection from erosion and storm events (Ellison, 2009; Krauss et al., 2010; Waycott et al., 2011).

SLR is reported as the most significant climate change threat to the survival of mangroves (Waycott et al., 2011). Loss of the seaward edge of mangroves at Hungry Bay, Bermuda, has been reported by Ellison (1993), who attributes this process to SLR and the inability of mangroves to tolerate increased water depth at the seaward margin. Elsewhere in the Caribbean and tropical Pacific, observations vary in regard to the potential for sedimentation rates in mangroves forests to keep pace with SLR (Krauss et al., 2003; McKee et al., 2007). In Kosrae and Pohnpei Islands (Federated States of Micronesia), Krauss et al. (2010) found significant variability in mangrove average soil elevation changes due to deposition from an accretion deficit of 4.95 mm yr^{-1} to an accretion surplus of 3.28 mm yr^{-1} relative to the estimated rate of SLR. Such surpluses are generally reported from high islands where additional

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

sediments can be delivered from terrestrial runoff. However, Rankey (2011) described natural seaward migration (up to 40 m) of some mangrove areas between 1969 and 2009 in atolls in Kiribati, suggesting sediment accretion can also occur in sediment-rich reefal areas and in the absence of terrigenous inputs.

The response of seagrass to climate change is also complex, regionally variable, and manifest in quite different ways. A study of seven species of seagrasses from tropical Green Island, Australia, highlighted the variability in response to heat and light stress (Campbell et al., 2006). Light reduction may be a limiting factor to seagrass growth due to increased water depth and sedimentation (Ralph et al., 2007). Ogston and Field (2010) observed that a 20-cm rise in sea level may double the suspended sediment loads and turbidity in shallow waters on fringing reefs of Molokai, Hawaiian Islands, with negative implications to photosynthetic species such as seagrass. Otherwise, temperature stress is most commonly reported as the main expected climate change impact on seagrass (e.g., Campbell et al., 2006; Waycott et al., 2011). Literature on seagrass diebacks in small islands is scarce but research in the Balearic Islands (Western Mediterranean) has shown that over a 6-year study, seagrass shoot mortality and recruitment rates were negatively influenced by higher temperature (Marbá and Duarte, 2010; see also Section 5.4.2.3 for further discussion of impacts on mangrove and seagrass communities).

29.3.2. Observed Impacts on Terrestrial Systems: Island Biodiversity and Water Resources

Climate change impacts on terrestrial biodiversity on islands, frequently interacting with several other drivers (Blackburn et al., 2004; Didham et al., 2005), fall into three general categories, namely: (1) ecosystem and species horizontal shifts and range decline; (2) altitudinal species range shifts and decline mainly due to temperature increase on high islands; and (3) exotic and pest species range increase and invasions mainly due to temperature increase in high-latitude islands. Owing to the limited area and isolated nature of most islands, these effects are generally magnified compared to continental areas and may cause species loss, especially in tropical islands with high numbers of endemic species. For example, in two low-lying islands in the Bahamas, Greaver and Sternberg (2010) found that during periods of reduced rainfall the shallow freshwater lens subsides and contracts landward and ocean water infiltrates further inland, negatively impacting on coastal strand vegetation. SLR has also been observed to threaten the long-term persistence of freshwater-dependent ecosystems within low-lying islands in the Florida Keys (Goodman et al., 2012). On Sugarloaf Key, Ross et al. (2009) found pine forest area declined from 88 to 30 ha from 1935 to 1991 due to increasing salinization and rising groundwater, with vegetation transitioning to more saline-tolerant species such as mangroves.

Although there are many studies that report observations associated with temperature increases in mid- and high-latitude islands, such as the Falkland Islands and Marion Islands in the south Atlantic and south Indian Ocean respectively (Le Roux et al., 2005; Bokhorst et al., 2007, 2008) and Svalbard in the Arctic (Webb et al., 1998), there are few equivalent studies in tropical small islands. A recent study of the tropical Mauritius kestrel indicates changing rainfall conditions in Mauritius over the last 50 years have resulted in this species having reduced reproductive success due to a mismatch between the timing of breeding and peak food abundance (Senapathi et al., 2011).

Increasing global temperatures may also lead to altitudinal species range shifts and contractions within high islands, with an upward creep of the tree line and associated fauna (Benning et al., 2002; Krushelnycky et al., 2013). For instance, in the central mountain ranges of the subtropical island of Taiwan, Province of China, historical survey and resurvey data from 1906 to 2006 showed that the upper altitudinal limits of plant distributions had risen by about 3.6 m yr^{-1} during the last century in parallel with rising temperatures in the region (Jump et al., 2012). Comparable effects also occur in the tropics such as in Hawaii Volcano National Park, where comparison of sample plots over a 40-year period from 1966/1967 to 2008 show fire-adapted grasses expanded upward along a warming tropical elevation gradient (Angelo and Daehler, 2013). Reduction in the numbers and sizes of endemic populations caused by such habitat constriction and changes in species composition in mountain systems may result in the demise and possibly extinction of endemic species (Pauli et al., 2007; Chen et al., 2009; Sekercioglu et al., 2008; Krushelnycky et al., 2013). Altitudinal temperature change has also been reported to influence the distribution of disease vectors such as mosquitoes, potentially threatening biota unaccustomed to such vectors (Freed et al., 2005; Atkinson and LaPointe, 2009).

Freshwater supply in small island environments has always presented challenges and has been an issue raised in all previous IPCC reports. On high volcanic and granitic islands, small and steep river catchments respond rapidly to rainfall events, and watersheds generally have restricted storage capacity. On porous limestone and low atoll islands, surface runoff is minimal and water rapidly passes through the substrate into the groundwater lens. Rainwater harvesting is also an important contribution to freshwater access, and alternatives such as desalination have had mixed success in small island settings owing to operational costs (White and Falkland, 2010).

Rapidly growing demand, land use change, urbanization, and tourism are already placing significant strain on the limited freshwater reserves in small island environments (Emmanuel and Spence, 2009; Cashman et al., 2010; White and Falkland, 2010). In the Caribbean, where there is considerable variation in the types of freshwater supplies utilized, concern over the status of freshwater availability has been expressed for at least the past 30 years (Cashman et al., 2010). There have also been economic and management failures in the water sector not only in the Caribbean (Mycoo, 2007) but also in small islands in the Indian (Payet and Agricole, 2006) and Pacific Oceans (White et al., 2007; Moglia et al., 2008a,b).

These issues also occur on a background of decreasing rainfall and increasing temperature. Rainfall records averaged over the Caribbean region for 100 years (1900–2000) show a consistent 0.18 mm yr^{-1} reduction in rainfall, a trend that is projected to continue (Jury and Winter, 2010). In contrast, analysis of rainfall data over the past 100 years from the Seychelles has shown substantial variability related to ENSO. Nevertheless an increase in average rainfall from 1959 to 1997 and an increase in temperature of approximately 0.25°C per decade have occurred (Payet and Agricole, 2006). Long-term reduction in streamflow (median reduction of 22 to 23%) has been detected in the Hawaiian Islands over the period 1913–2008, resulting in reduced freshwater availability for both human use and ecological processes (Bassiouni and Oki, 2013). Detection of long-term statistical change in precipitation is an important prerequisite toward a better understanding the impacts of climate change in small island hydrology and water resources.

There is a paucity of empirical evidence linking saline (seawater) intrusion into fresh groundwater reserves due simply to incremental SLR at this time (e.g., Rozell and Wong, 2010). However, this dynamic must be the subject of improved research given the importance of groundwater aquifers in small island environments. White and Falkland's (2010) review of existing small island studies indicates that a sea level increase of up to 1 m would have negligible salinity impacts on atoll island groundwater lenses so long as there is adequate vertical accommodation space, island shores remain intact, rainfall patterns do not change, and direct human impacts are managed. However, wave overtopping and wash-over can be expected to become more frequent with SLR, and this has been shown to impact freshwater lenses dramatically. On Pukapuka Atoll, Cook Islands, storm surge over-wash occurred in 2005. This caused the freshwater lenses to become immediately brackish and took 11 months to recover to conductivity levels appropriate for human use (Terry and Falkland, 2010). The ability of the freshwater lens to float upward within the substrate of an island in step with incremental SLR also means that in low-lying and central areas of many atoll islands the lens may pond at the surface. This phenomenon already occurs in central areas of Fongafale Island, Tuvalu, and during extreme high "king" tides large areas of the inner part of the island become inundated with brackish waters (Yamano et al., 2007; Locke, 2009).

29.3.3. Observed Impacts on Human Systems in Small Islands

29.3.3.1. Observed Impacts on Island Settlements and Tourism

While traditional settlements on high islands in the Pacific were often located inland, the move to coastal locations was encouraged by colonial and religious authorities and more recently through the development of tourism (Barnett and Campbell, 2010). Now the majority of settlement, infrastructure, and development are located on lowlands along the coastal fringe of small islands. In the case of atoll islands, all development and settlement is essentially coastal. It follows that populations, infrastructure, agricultural areas, and fresh groundwater supplies are all vulnerable to extreme tides, wave and surge events, and SLR (Walsh et al., 2012). Population drift from outer islands or from inland, together with rapid population growth in main centers and lack of accommodation space, drives growing populations into ever more vulnerable locations (Connell, 2012). In addition, without adequate resources and planning, engineering solutions such as shoreline reclamation also place communities and infrastructure in positions of increased risk (Yamano et al., 2007; Duvat, 2013).

Many of the environmental issues raised by the media relating to Tuvalu, the Marshall Islands, and Maldives are primarily relevant to the major population center and its surrounds, which are Funafuti, Majuro, and Male, respectively. As an example, Storey and Hunter (2010) indicate the "Kiribati" problem does not refer to the whole of Kiribati but rather to the southern part of Tarawa atoll, where preexisting issues of severe overcrowding, proliferation of informal housing and unplanned settlement, inadequate water supply, poor sanitation and solid waste disposal, pollution, and conflict over land ownership are of concern. They argue that these problems require immediate resolution if the vulnerability of the South Tarawa community to the "real and alarming threat" of climate change is to be managed effectively (Storey and Hunter, 2010).

On Majuro atoll, rapid urban development and the abandonment of traditional settlement patterns has resulted in movement from less vulnerable to more vulnerable locations on the island (Spennemann, 1996). Likewise, geophysical studies of Fongafale Island, the capital of Tuvalu, show that engineering works during World War II, and rapid development and population growth since independence, have led to the settlement of inappropriate shoreline and swampland areas, leaving communities in heightened conditions of vulnerability (e.g., Yamano et al., 2007). Ascribing direct climate change impacts in such disturbed environments is problematic owing to the existing multiple lines of stress on the island's biophysical and social systems. However, it is clear that such preexisting conditions of vulnerability add to the threat of climate change in such locations. Increased risk can also result from lack of awareness, particularly in communities in rural areas and outer islands ("periphery") of archipelagic countries such as Cook Islands, Fiji, Kiribati, and Vanuatu, whose climate change knowledge often contrasts sharply with that of communities in the major centers ("core"). In the core, communities tend to be better informed and have higher levels of awareness about the complex issues associated with climate change than in the periphery (Nunn et al., 2013).

The issue of "coastal squeeze" remains a concern for many small islands as there is a constant struggle to manage the requirements for physical development against the need to maintain ecological balance (Fish et al., 2008; Gero et al., 2011; Mycoo, 2011). Martinique in the Caribbean exemplifies the point, where physical infrastructure prevents the beach and wetlands from retreating landward as a spontaneous adaptation response to increased rates of coastal erosion (Schleupner, 2008). Moreover, intensive coastal development in the limited coastal zone, combined with population growth and tourism, has placed great stress on the coast of some islands and has resulted in dense aggregations of infrastructure and people in potentially vulnerable locations.

Tourism is an important weather and climate-sensitive sector on many small islands and has been assessed on several occasions, including in previous IPCC assessments. There is currently no evidence that observed climatic changes in small island destinations or source markets have permanently altered patterns of demand for tourism to small islands, and the complex mix of factors that actually determines destination choices under a changing climate still need to be fully evaluated (Scott et al., 2012a). However, there are cases reported that clearly show severe weather-related events in a destination country (e.g., heavy, persistent rainfall in Martinique: Hubner and Gössling, 2012; hurricanes in Anguilla: Forster et al., 2012) can significantly influence visitors' perception of the desirability of the location as a vacation choice.

Climate can also impact directly on environmental resources that are major tourism attractions in small islands. Widespread resource degradation challenges such as beach erosion and coral bleaching have been found to negatively impact the perception of destination attractiveness in various locations, for example, in Martinique (Schleupner, 2008), Barbados, and Bonaire (Uyarra et al., 2005). Similarly, dive tourists are well aware of coral bleaching, particularly the experienced diver segment (Gössling et al., 2012a; Klint et al., 2012). Therefore more acute impacts are felt by tourism operators and resorts that cater to these markets. Houston (2002) and Buzinde et al. (2010) also indicate that beach erosion may similarly affect accommodation prices in some destinations. Consequently, some countries have begun to invest in a variety of resource restoration initiatives including artificial beach nourishment, coral and mangrove restoration, and the establishment of marine parks and protected areas (McClanahan et al., 2008; Mycoo and Chadwick, 2012). There is no analysis of how widespread such investments are or their capability to cope effectively with future climate change. The tourism industry and investors are also beginning to consider the climate risk of tourism operations (Scott et al., 2012b), including those associated with the availability of freshwater. Freshwater is limited on many small islands, and changes in its availability or quality during drought events linked to climate change have adverse impacts on tourism operations (UNWTO, 2012). Tourism is a seasonally significant water user in many island destinations, and in times of drought concerns over limited supply for residents and other economic activities become heightened (Gössling et al., 2012b). The increasing use of desalination plants is one adaptation to reduce the risk of water scarcity in tourism operations.

29.3.3.2. Observed Impacts on Human Health

Globally, the effects of climate change on human health will be both direct and indirect, and are expected to exacerbate existing health risks, especially in the most vulnerable communities, where the burden of disease is already high (refer to Sections 11.3, 11.5, 11.6.1). Many small island states currently suffer from climate-sensitive health problems, including morbidity and mortality from extreme weather events, certain vector- and food- and water-borne diseases (Lozano, 2006; Barnett and Campbell, 2010; Cashman et al., 2010; Pulwarty et al., 2010; McMichael and Lindgren, 2011). Extreme weather and climate events such as tropical cyclones, storm surges, flooding, and drought can have both short- and long-term effects on human health, including drowning, injuries, increased disease transmission, and health problems associated with deterioration of water quality and quantity. Most small island nations are in tropical areas with weather conducive to the transmission of diseases such as malaria, dengue, filariasis, and schistosomiasis.

The linkages between human health, climate variability, and seasonal weather have been demonstrated in several recent studies. The Caribbean has been identified as a "highly endemic zone for leptospirosis," with Trinidad and Tobago, Barbados, and Jamaica representing the highest annual incidence (12, 10, and 7.8 cases per 100,000, respectively) in the world, with only the Seychelles being higher (43.2 per 100,000 population) (Pappas et al., 2008). Studies conducted in Guadeloupe demonstrated a link between El Niño occurrence and leptospirosis incidence, with rates increasing to 13 per 100,000 population in El Niño years, as opposed to 4.5 cases per 100,000 inhabitants in La Niña and neutral years (Herrmann-Storck et al., 2008). In addition, epidemiological studies conducted in Trinidad reviewed the incidence of leptospirosis during the period 1996–2007 and showed seasonal patterns in the occurrence of confirmed leptospirosis cases, with significantly ($P < 0.001$) more cases occurring in the wet season, May to November (193 cases), than during the dry season, December to May (66 cases) (Mohan et al., 2009). Recently changes in the epidemiology of leptospirosis have been detected, especially in tropical islands, with the main factors being climatic and anthropogenic ones (Pappas et al., 2008). These factors may be enhanced with increases in ambient temperature and changes in precipitation, vegetation, and water availability as a consequence of climate change (Russell, 2009).

In Pacific islands the incidence of diseases such as malaria and dengue fever has been increasing, especially endemic dengue in Samoa, Tonga, and Kiribati (Russell, 2009). Although studies conducted so far in the Pacific have established a direct link only between malaria, dengue, and climate variability, these and other health risks including from cholera are projected to increase as a consequence of climate change (Russell, 2009; see also Sections 11.2.4-5 for detailed discussion on the link between climate change and projected increases in the outbreak of dengue and cholera). Dengue incidence is also a major health concern in other small island countries, including Trinidad and Tobago, Singapore, Cape Verde, Comoros, and Mauritius (Koh et al., 2008; Chadee, 2009; Van Kleef et al., 2010; Teles, 2011). In the specific cases of Trinidad and Tobago and Singapore the outbreaks have been significantly correlated with rainfall and temperature, respectively (Chadee et al., 2007; Koh et al., 2008).

Previous IPCC assessments have consistently shown that human health on islands can be seriously compromised by lack of access to adequate, safe freshwater and adequate nutrition (Nurse et al., 2001; Mimura et al., 2007). Lovell (2011) notes that in the Pacific many of the anticipated health effects of climate change are expected to be indirect, connected to the increased stress and declining well-being that comes with property damage, loss of economic livelihood, and threatened communities. There is also a growing concern in island communities in the Caribbean Sea and Pacific and Indian Oceans that freshwater scarcity and more intense droughts and storms could lead to a deterioration in standards of sanitation and hygiene (Cashman et al., 2010; McMichael and Lindgren, 2011). In such circumstances, increased exposure to a range of health risks including communicable (transmissible) diseases would be a distinct possibility.

Ciguatera fish poisoning (CFP) occurs in tropical regions and is the most common non-bacterial food-borne illness associated with consumption of fish. Distribution and abundance of the organisms that produce these toxins, chiefly dinoflagellates of the genus *Gambierdiscus*, are reported to correlate positively with water temperature. Consequently, there is growing concern that increasing temperatures associated with climate change could increase the incidence of CFP in the island regions of the Caribbean (Morrison et al., 2008; Tester et al., 2010), Pacific (Chan et al., 2011; Rongo and van Woesik, 2011), the Mediterranean (Aligizaki and Nikolaidis, 2008; see also Section 29.5.5), and the Canary Islands in the Atlantic (Pérez-Arellano et al., 2005). A recent Caribbean study sought to characterize the relationship between SSTs and CFP incidence

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

and to determine the effects of temperature on the growth rate of organisms responsible for CFP. Results from this work show that in the Lesser Antilles high rates occur in areas that experience the warmest water temperatures and that show the least temperature variability (Tester et al., 2010). There are also high rates in the Pacific in Tokelau, Tuvalu, Kiribati, Cook Islands, and Vanuatu (Chan et al., 2011).

The influence of climatic factors on malaria vector density and parasite development is well established (Chaves and Koenraadt, 2010; Béguin et al., 2011). Previous studies have assessed the potential influence of climate change on malaria, using deterministic or statistical models (Martens et al., 1999; Pascual et al., 2006; Hay et al., 2009; Parham and Michael, 2010). Although the present incidence of malaria on small islands is not reported to be high, favorable environmental and social circumstances for the spread of the disease are present in some island regions and are expected to be enhanced under projected changes in climate in Papua New Guinea, Guyana, Suriname, and French Guyana (Michon et al., 2007; Figueroa, 2008; Rawlins et al., 2008). In the Caribbean, the occurrence of autochthonous malaria in non-endemic island countries in the last 10 years suggests that all of the essential malaria transmission conditions now exist. Rawlins et al. (2008) call for enhanced surveillance, recognizing the possible impact of climate change on the spread of the *Anopheles* mosquito vector and malaria transmission.

29.3.3.3. Observed Impacts of Climate Change on Relocation and Migration

Evidence of human migration as a response to climate change is scarce for small islands. Although there is general agreement that migration is usually driven by multiple factors (Black et al., 2011), several authors highlight the lack of empirical studies of the effect of climate-related factors, such as SLR, on island migration (Mortreux and Barnett, 2009; Lilleør and Van den Broeck, 2011). Furthermore, there is no evidence of any government policy that allows for climate "refugees" from islands to be accepted into another country (Bedford and Bedford, 2010). This finding contrasts with the early desk-based estimates of migration under climate change such as the work of Myers (2002). These early studies have been criticized as they fail to acknowledge the reality of climate impacts on islands, the capacity of islands and islanders to adapt, or the actual drivers of migration (Barnett and O'Neill, 2012).

Studies of island migration commonly reveal the complexity of a decision to migrate and rarely identify a single cause. For example, when looking at historical process of migration within the Mediterranean, it appears that rising levels of income, coupled with a decreased dependence on subsistence agriculture, has left the Mediterranean less vulnerable to all environmental stressors, resulting in a reduced need for mobility to cope with environmental or climatic change (de Haas, 2011). Studies from the Pacific have also shown that culture, lifestyle, and a connection to place are more significant drivers of migration than climate (Barnett and Webber, 2010). For example, a Pacific Access Category of migration has been agreed between New Zealand and Tuvalu that permits 75 Tuvaluans to migrate to New Zealand every year (Kravchenko, 2008). Instead of enabling climate-driven migration, this agreement is designed to facilitate economic and social migration as part of the Pacific Island lifestyle (Shen and Gemenne, 2011). To date there is no unequivocal evidence that reveals migration from islands is being driven by anthropogenic climate change.

There is, however, some evidence that environmental change has played a role in Pacific Island migration in the past (Nunn, 2007). In the Pacific, environmental change has been shown to affect land use and land rights, which in turn have become drivers of migration (Bedford and Bedford, 2010). In a survey of 86 case studies of community relocations in Pacific Islands, Campbell et al. (2005) found that environmental variability and natural hazards accounted for 37 communities relocating. In the Pacific, where land rights are a source of conflict, climate change could increase levels of stress associated with land rights and impact on migration (Campbell, 2010; Weir and Virani, 2011). Although there is not yet a climate fingerprint on migration and resettlement patterns in all small islands, it is clear that there is the potential for human movement as a response to climate change. To understand better the impact of climate change on migration there is an urgent need for robust methods to identify and measure the effects of the drivers of migration on migration and resettlement.

29.3.3.4. Observed Impacts on Island Economies

The economic and environmental vulnerabilities of small islands states are well documented (Briguglio et al., 2009, Bishop, 2012). Such vulnerabilities, which render the states at risk of being harmed by economic and environmental conditions, stem from intrinsic features of these vulnerable states, and are not usually governance induced. However, governance does remain one of the challenges for island countries in the Pacific in the pursuit of sustainable development through economic growth (Prasad, 2008). Economic vulnerability is often the result of a high degree of exposure to economic conditions often outside the control of small island states, exacerbated by dependence on a narrow range of exports and a high degree of dependence on strategic imports, such as food and fuel (Briguglio et al., 2009). This leads to economic volatility, a condition that is harmful for the economy of the islands (Guillaumont, 2010).

There are other economic downsides associated with small size and insularity. Small size leads to high overhead cost per capita, particularly in infrastructural outlays. This is of major relevance to climate change adaptation that often requires upgrades and redesign of island infrastructure. Insularity leads to high cost of transport per unit, associated with purchases of raw materials and industrial supplies in small quantities, and sales of local produced products to distant markets. These disadvantages are associated with the inability of small islands to reap the benefits of economies of scale, resulting in a high cost of doing business in small islands (Winters and Martins, 2004).

High costs are also associated with the small size of island states when impacted by extreme events such as hurricanes and droughts. On small islands such events often disrupt most of the territory, especially on single-island states, and have a very large negative impact on the state's GDP, in comparison with larger and more populous states where individual events generally only affect a small proportion of the country and have a small impact on its GDP (Anthoff et al., 2010). Moreover, the dependence of many small islands on a limited number of economic

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Frequently Asked Questions

FAQ 29.2 | Why is the cost of adaptation to climate change so high in small islands?

Adaptation to climate change that involves infrastructural works generally requires large up-front overhead costs, which in the case of small islands cannot be easily downscaled in proportion to the size of the population or territory. This is a major socioeconomic reality that confronts many small islands, notwithstanding the benefits that could accrue to island communities through adaptation. Referred to as "indivisibility" in economics, the problem can be illustrated by the cost of shore protection works aimed at reducing the impact of sea level rise. The unit cost of shoreline protection per capita in small islands is substantially higher than the unit cost for a similar structure in a larger territory with a larger population. This scale-reality applies throughout much of a small island economy including the indivisibility of public utilities, services, and all forms of development. Moreover, the relative impact of an extreme event such as a tropical cyclone that can affect most of a small island's territory has a disproportionate impact on that state's gross domestic product, compared to a larger country where an individual event generally affects a small proportion of its total territory and its GDP. The result is relatively higher adaptation and disaster risk reduction costs per capita in countries with small populations and areas—especially those that are also geographically isolated, have a poor resource base, and have high transport costs.

sectors such as tourism, fisheries, and agricultural crops, all of which are climate sensitive, means that on the one hand climate change adaptation is integral to social stability and economic vitality but that government adaptation efforts are constrained because of the high cost on the other.

29.3.4. Detection and Attribution of Observed Impacts of Climate Change on Small Islands

While exceptional vulnerability of many small islands to future climate change is widely accepted, the foregoing analysis indicates that the scientific literature on observed impacts is quite limited. Detection of past and recent climate change impacts is challenging owing to the presence of other anthropogenic drivers, especially in the constrained environments of small islands. Attribution is further challenged by the strong influence of natural climate variability compared to gradual incremental change of climate drivers. Notwithstanding these limitations, a summary of the relationship between detection and attribution to climate change of several of the phenomena described in the preceding sections has been prepared. Figure 29-2 reflects the degree of confidence in the link between observed changes in several components of the coastal, terrestrial, and human systems of small islands and the drivers of climate change.

29.4. Projected Integrated Climate Change Impacts

Small islands face many challenges in using climate change projections for policy development and decision making (Keener et al., 2012). Among these is the inaction inherent in the mismatch of the short-term time scale on which government decisions are generally taken compared with the long-term time scale required for decisions related to climate change. This is further magnified by the general absence of credible regional socioeconomic scenarios relevant at the spatial scale at which most decisions are taken. Scenarios are an important tool to help decision makers disaggregate vulnerability to the direct physical impacts of the climate signal from the vulnerability associated with socioeconomic conditions and governance. There is, however, a problem in generating formal climate scenarios at the scale of small islands because they are generally much smaller than the resolution of the global climate models. This is because the grid squares in the Global Circulation Models (GCMs) used in the SRES scenarios over the last decade were between 200 and 600 km^2, which provides inadequate resolution over the land areas of most small islands. This has recently improved with the new Representative Concentration Pathway (RCP) scenario GCMs with grid boxes generally between 100 and 200 km^2 in size.

The scale problem has been usually addressed by the implementation of statistical downscaling models that relate GCM output to the historical climate of a local small island data point. The limitation of this approach is the need for observed data ideally for at least 3 decades for a number of representative points on the island, in order to establish the statistical relationships between GCM data and observations. In most small islands long-term quality-controlled climate data are generally sparse, so that in widely dispersed islands such as in the Pacific, observational records are usually supplemented with satellite observations combined with dynamical downscaling computer models (Australian Bureau of Meteorology and CSIRO, 2011a; Keener et al., 2012). However, where adequate local data are available for several stations for at least 30 years, downscaling techniques have demonstrated that they can provide projections at fine scales ranging from about 10 to 25 km^2 (e.g., Charlery and Nurse, 2010; Australian Bureau of Meteorology and CSIRO, 2011a). Even so, most projected changes in climate for the Caribbean Sea, Pacific and Indian Oceans, and Mediterranean islands generally apply to the region as a whole, and this may be adequate to determine general trends in regions where islands are close together.

29.4.1. Non-formal Scenario-based Projected Impacts

Scenarios are often constructed by using a qualitative or broad order of magnitude climate projections approach based on expected changes

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

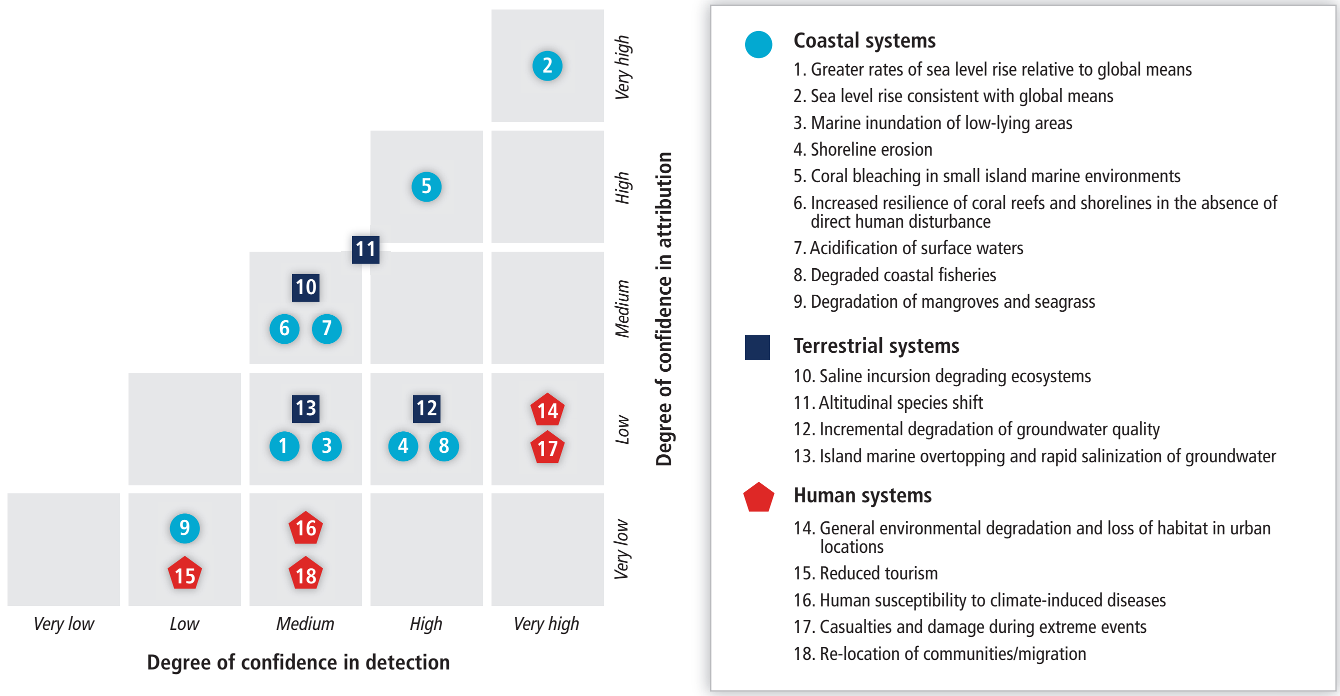


Figure 29-2 | A comparison of the degree of confidence in the detection of observed impacts of climate change on tropical small islands with the degree of confidence in attribution to climate change drivers at this time. For example, the blue symbol No. 2 (Coastal Systems) indicates there is *very high confidence* in both the detection of "sea level rise consistent with global means" and its attribution to climate change drivers; whereas the red symbol No. 17 (Human Systems) indicates that although confidence in detection of "casualties and damage during extreme events" is *very high*, there is at present *low confidence* in the attribution to climate change. It is important to note that *low confidence* in attribution frequently arises owing to the limited research available on small island environments.

in some physical climate signal from literature review rather than projections based on direct location-specific modeling. Usually this is proposed as a "what if" question that is then quantified using a numerical method. For example, in the Pacific, digital elevation models of Fiji's islands have been used to identify high risk areas for flooding based on six scenarios for SLR from 0.09 to 0.88 m in combination with six scenarios for storm surge with return intervals from 1 to 50 years (Gravelle and Mimura, 2008). Another example of qualitative modeling from the Pacific is a case study from Nauru that uses local data and knowledge of climate to assess the GCM projections. It suggests that Nauru should plan for continued ENSO variability in the future with dry years during La Niña and an overall increase in mean rainfall and extreme rainfall events. Climate adaptation concerns that arise include water security and potential changes in extreme wet events that affect infrastructure and human health (Brown et al., 2013a). Climate change also poses risks for food security in the Pacific Islands, including agriculture and fisheries (Barnett, 2011).

Projections have also been used in the islands of the Republic of Baharain to estimate proneness to inundation for SLR of 0.5, 1.0, and 1.5 m (Al-Jeneid et al., 2008). Similarly, in the Caribbean the elevation equivalent of a projected SLR of 1 m has been superimposed on topographic maps to estimate that 49 to 60% of tourist resort properties would be at risk of beach erosion damage, potentially transforming the competitive position and sustainability of coastal tourism destinations in the region (Scott et al., 2012c). This method has also been used to quantify the area loss for more than 12,900 islands and more than 3000 terrestrial vertebrates in the tropical Pacific region for three SLR scenarios. The study estimated that for SLR of 1 m, 37 island endemic species in this region risk complete inundation (Wetzel et al., 2013).

29.4.2. Projected Impacts for Islands Based on Scenario Projections

Another approach to scenario development is to use the region-specific projections more directly. It is worth noting that the broad synthesis in the AR4 of medium emissions climate scenario projections for small island regions (Mimura et al., 2007) shows concordance with the new RCP scenarios (see Table 29-1 and new RCP projections in Figure 29-3). For example, the SRES A1B medium emissions scenario suggests about a 1.8°C to 2.3°C median annual increase in surface temperature in the Caribbean Sea and Indian and Pacific Ocean small islands regions by 2100 compared to a 1980–1999 baseline, with an overall annual decrease in precipitation of about 12% in the Caribbean (WGI AR4 Table 11.1; WGI AR5 Section 14.7.4) and a 3 to 5% increase in the Indian and Pacific Ocean small island regions. Comparative projections for the new RCP4.5 scenario suggests about a 1.2°C to 2.3°C increase in surface temperature by 2100 compared to a 1986–2005 baseline and a decrease in precipitation of about 5 or 6% in the Caribbean and Mediterranean, respectively, signaling potential future problems for agriculture and water availability compared to a 1 to 9% increase in the Indian and Pacific Ocean small islands regions (Table 29-1). However, there are important spatial and high-island topography differences. Thus, for example, among the more dispersed Pacific Islands where the equatorial regions are likely to get wetter and the subtropical high pressure belts

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Table 29-1 | Climate change projections for the intermediate low (500–700 ppm CO_2e) Representative Concentration Pathway 4.5 (RCP4.5) scenario for the main small island regions. The table shows the 25th, 50th (median), and 75th percentiles for surface temperature and precipitation based on averages from 42 Coupled Model Intercomparison Project Phase 5 (CMIP5) global models (adapted from WGI AR5 Table 14.1). Mean net regional sea level change is evaluated from 21 CMIP5 models and includes regional non-scenario components (adapted from WGI AR5 Figure 13-20).

Small island region	RCP4.5 annual projected change for 2081–2100 compared to 1986–2005						
	Temperature (°C)			Precipitation (%)			Sea level (m)
	25%	50%	75%	25%	50%	75%	Range
Caribbean	1.2	1.4	1.9	–10	–5	–1	0.5–0.6
Mediterranean	2.0	2.3	2.7	–10	–6	–3	0.4–0.5
Northern tropical Pacific	1.2	1.4	1.7	0	1	4	0.5–0.6
Southern Pacific	1.1	1.2	1.5	0	2	4	0.5–0.6
North Indian Ocean	1.3	1.5	2.0	5	9	20	0.4–0.5
West Indian Ocean	1.2	1.4	1.8	0	2	5	0.5–0.6

drier (as reported by WGI AR5) in regions directly affected by the South Pacific Convergent Zone (SPCZ) and western portion of the Inter-Tropical Convergent Zone (ITCZ), the rainfall outlook is uncertain (WGI AR5 Section 14.7.13). Projections for the Mediterranean islands also differ from those for the tropical small islands. Throughout the Mediterranean region, the length, frequency, and/or intensity of warm spells or heat waves are *very likely* to increase to the year 2100 (WGI AR5 Section 14.7.6). SLR projections in the small islands regions for RCP4.5 are similar to the global projections of 0.41 to 0.71 m (WGI AR5 Section 13.5.1), ranging from 0.5 to 0.6 m by 2100 compared to 1986–2005 in the Caribbean Sea and Pacific and Indian Oceans to 0.4 to 0.5 m in the Mediterranean and north Indian Ocean (Table 29-1).

In the main regions in which most tropical or subtropical small island states are located, there are few independent peer-reviewed scientific publications providing downscaled climate data projections, and even less illustrating the experience gained from their use for policy making. A possible 2°C temperature increase by the year 2100 has potentially far-reaching consequences for sentinel ecosystems such as coral reefs that are important to tropical islands (see Section 6.2.2.4.4). This is because "degree heating months" (DHMs) greater than 2°C per month are the determining threshold for severe coral bleaching (Donner, 2009). For example, in a study of SST across all coral reef regions using GCM ensemble projections forced with five different SRES future emissions scenarios, Donner (2009) concluded that even warming in the future from the current accumulation of GHGs in the atmosphere could cause more than half of the world's coral reefs to experience harmfully frequent thermal stress by 2080. Further, this timeline could be brought forward to as early as 2030 under the A1B medium emissions scenario. He further stated that thermal adaptation of 1.5°C would delay the thermal stress forecast by only 50 to 80 years. Donner (2009) also estimated the year of likelihood of a severe mass coral bleaching event due more than once every 5 years to be 2074 in the Caribbean, 2088 in the western Indian Ocean, 2082 in the central Indian Ocean, 2065 in Micronesia, 2051 in the central Pacific, 2094 in Polynesia, and 2073 in the eastern Pacific small islands regions. Using the new RCP scenarios by comparison, van Hooidonk et al. (2013) found that the onset of annual bleaching conditions is associated with about 510 ppm CO_2-eq. The conclusion based on outputs from a wide range of emissions scenarios and models is that preserving more than 10% of coral reefs worldwide would require limiting warming to less than 1.5°C (1.3°C to 1.8°C Atmosphere-Ocean General Circulation Model (AOGCM) range) compared to pre-industrial levels (Frieler et al., 2013).

Small island economies can also be objectively shown to be at greater risk from SLR in comparison to other geographic areas because most of their population and infrastructure are in the coastal zone. This is demonstrated in a study using the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model to assess the economic impact of substantial SLR in a range of socioeconomic scenarios downscaled to the national level, including the four SRES storylines (Anthoff et al., 2010). Although this study showed that, in magnitude, a few regions will experience most of the absolute costs of SLR by 2100, especially East Asia, North America, Europe, and South Asia, these same results when expressed as percent of GDP showed that most of the top ten and four of the top five most impacted are small islands from the Pacific (Federated States of Micronesia, Palau, Marshall Islands, Nauru) and Caribbean (Bahamas). The point is made that the damage costs for these small island states are enormous in relation to the size of their economies (Nicholls and Tol, 2006) and that, together with deltaic areas, they will find it most difficult to locally raise the finances necessary to implement adequate coastal protection (Anthoff et al., 2010).

In the Caribbean, downscaled climate projections have been generated for some islands using the Hadley Centre PRECIS (Providing REgional Climates for Impact Studies) regional model (Taylor et al., 2007; Stephenson et al., 2008). For the SRES A2 and B2 scenarios, the PRECIS regional climate model projects an increase in temperature across the Caribbean of 1°C to 4°C compared to a 1960–1990 baseline, with increasing rainfall during the latter part of the wet season from November to January in the northern Caribbean (i.e., north of 22°N) and drier conditions in the southern Caribbean linked to changes in the Caribbean Low Level Jet (CLLJ) with a strong tendency to drying in the traditional wet season from June to October (Whyte et al., 2008; Campbell et al., 2011; Taylor et al., 2013). Projected lengthening seasonal dry periods, and increasing frequency of drought are expected to increase demand for water throughout the region under the SRES A1B scenario (Cashman et al., 2010). Decrease in crop yield is also projected in Puerto Rico for the SRES B1 (low), A2 (mid to high), and A1F1 scenarios during September although increased crop yield is suggested during February (Harmsen et al., 2009). Using a tourism demand model linked to the SRES A1F1, A2, B1, and B2 scenarios, the projected climate change heating and drying impacts are also linked to potential aesthetic, physical, and thermal effects that are estimated to cause a change in total regional tourist expenditure of about +321, +356, –118, and -146 million US$ from the least to the most severe emissions scenario, respectively (Moore, 2010).

In the Indian Ocean, representative downscaled projections have been generated for Australia's two Indian Ocean territories, the Cocos (Keeling) Islands and Christmas Island using the CSIRO (Commonwealth Scientific and Industrial Research Organisation) Mark 3.0 climate model with the SRES A2 high-emissions scenario (Maunsell Australia Pty Ltd., 2009). Future climate change projections for the two islands for 2070 include

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

an approximate 1.8°C increase in air temperature by 2070, probable drier dry seasons and wet seasons, about a 40-cm rise in sea level, and a decrease in the number of intense tropical cyclones.

In the western tropical Pacific, extensive climate projections have been made for several Pacific Island countries based on downscaling from an ensemble of models (Australian Bureau of Meteorology and CSIRO, 2011b). The temperature projections in this region dominated by oceans seem less than those seen globally, ranging from +1.5 to 2.0°C for the B1 low-emissions scenario to +2.5 to 3.0°C for the A2 high-emissions scenario by the year 2090 relative to a 20-year period centered on 1990. Notably, extreme rainfall events that currently occur once every 20 years on average are generally simulated to occur four times per 20-year period, on average, by 2055 and seven times per 20-year period, on average, by 2090 under the A2 (high-emissions) scenario (Australian Bureau of Meteorology and CSIRO, 2011b). The results are not very different from the tropical Pacific RCP4.5 projections, with projected temperature increases of about +1.2 to 1.4°C by 2100 and an increase in rainfall of about 4% (Table 29-1). A comprehensive assessment of the vulnerability of the fisheries and aquaculture sectors to climate change in 22 Pacific island countries and territories focused on two future time frames (2035 and 2100) and two SRES emissions scenarios, B1 (low emissions) and A2 (high emissions) (Bell et al., 2013). Many anticipated changes in habitat and resource availability such as coral reef-based fisheries are negative. By contrast, projected changes in tuna fisheries and freshwater aquaculture/fisheries can be positive with implications for government revenue and island food security (Bell et al., 2013). Simulation studies on changes in stocks of skipjack and bigeye tuna in the tropical Pacific area summarized in Table 29-2 and also discussed in Sections 7.4.2.1 and 30.6.2.1.1. Some of these projected changes may favor the large international fishing fleets that can shift operations over large distances compared to local, artisanal fishers (Polovina et al., 2011).

In the Mediterranean islands of Mallorca, Corsica, Sardinia, Crete, and Lesvos, Gritti et al. (2006) simulated the terrestrial vegetation biogeography and distribution dynamics under the SRES A1F1 and B1 scenarios to the year 2050. The simulations indicate that the effects of climate change are expected to be negligible within most ecosystems except for mountainous areas. These areas are projected to be eventually occupied by exotic vegetation types from warmer, drier conditions. Cruz et al. (2009) report similar results for the terrestrial ecosystems of Madeira Island in the Atlantic. Downscaled SRES A2 and B2 scenarios for the periods 2040–2069 and 2070–2099 suggest that the higher altitude native humid forest, called the Laurissilva, may expand upward in altitude, which could lead to a severe reduction of the heath woodland which because it has little upward area to shift may reduce in range or disappear at high altitudes, resulting in the loss of rare and endemic species within this ecosystem.

Table 29-2 | Summary of projected percentage changes in tropical Pacific tuna catches by 2036 and 2100 relative to 1980–2000 for SRES scenarios A2 and B1, and the estimated resulting percentage change to government revenue (after Tables 12.7 and 12.9 of Bell et al., 2011).

Tuna fishery		Change in catch (%)		
		2035: B1/A2	2100: B1	2100: A2
Skipjack tuna	Western fishery	+11	–0.2	–21
	Eastern fishery	+37	+43	+27
	Total	+19	+12	–7
Bigeye tuna	Western fishery	–2	–12	–34
	Eastern fishery	+3	–4	–18
	Total	+0.3	–9	–27
Country		**Change in government revenue (%)**		
		2035: B1/A2	**2100: B1**	**2100: A2**
Federated States of Micronesia		+1 to +2	0 to +1	–1 to –2
Solomon Islands		0 to +0.2	0 to –0.3	0 to +0.8
Kiribati		+11 to +18	+13 to +21	+7 to +12
Tuvalu		+4 to +9	+4 to +10	+2 to +6

29.4.3. Representative Concentration Pathway Projections and Implications for Small Islands

Utilizing updated historical GHG emissions data the scientific community has produced future projections for four plausible new global RCPs to explore a range of global climate signals up to the year 2100 and beyond (e.g., Moss et al., 2010). Typical model ensemble representations of low, intermediate low, intermediate high, and high RCP projections for annual temperature and precipitation in some small islands regions are presented in Figure 29-3. Highlighted in Figure 29-3 is the ensemble mean of each RCP. A more comprehensive compilation of quarterly global RCP projections can be found in the WGI AR5 Annex I: Atlas of Global and Regional Climate Projections.

During negotiations toward a new multilateral climate change regime Small Island Developing States (SIDS) have advocated that any agreement should be based on Global Mean Surface Temperature (GMST) increase "well below" 1.5°C above pre-industrial levels (Hare et al., 2011; Riedy and McGregor, 2011). Inspection of column 1 in Figure 29-3 suggests that for the Caribbean, Indian Ocean, and Pacific SIDS in the tropics, the median projected regional increase is in the range 0.5°C to 0.9°C by 2100 compared to 1986–2005. This, together with the temperature change that has already occurred since the Industrial Revolution, suggests that a temperature "well below" 1.5°C is unlikely to be achieved with the lowest RCP2.6 projection (Peters et al., 2013). By comparison, temperature projections for the intermediate low RCP4.5 scenario (Table 29-1; Figure 29-3) suggest possible 1.2°C to 1.5°C temperature increases in Caribbean, Indian Ocean, and Pacific SIDS by 2100 compared to 1986–2005. Similarly, the projections for the Mediterranean would be about a 2.3°C increase by 2100 compared to 1986–2005 that would represent a 2.7°C increase compared to pre-industrial temperatures. Associated with this change, the Caribbean and Mediterranean regions may experience a noticeable decrease in mean rainfall while the Indian and Pacific Ocean SIDS may experience increased rainfall. These trends accelerate moderately for RCP6.0 and steeply for RCP8.5 (Table 29-1).

29.5. Inter- and Intra-regional Transboundary Impacts on Small Islands

Available literature since AR4 has highlighted previously less well understood impacts on small islands that are generated by processes

29

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

originating in another region or continent well beyond the borders of an individual archipelagic nation or small island. These are inter-regional transboundary impacts. Intra-regional transboundary impacts originate from a within-region source (e.g., the Caribbean). Some transboundary processes may have positive effects on the receiving small island or nation, though most that are reported have negative impacts. Deciphering a climate change signal in inter- and intra-regional transboundary impacts on small islands is not easy and usually involves a chain of linkages tracing back from island-impact to a distant climate or climate-related bio-physical or human process. Some examples are given below.

29.5.1. Large Ocean Waves from Distant Sources

Unusually large deep ocean swells, generated from sources in the mid- and high latitudes by extratropical cyclones (ETCs) cause considerable damage on the coasts of small islands thousands of kilometers away in the tropics. Impacts include sea flooding and inundation of settlements, infrastructure, and tourism facilities as well as severe erosion of beaches (see also Section 5.4.3.4). Examples from small islands in the Pacific and Caribbean are common, though perhaps the most significant instance, in terms of a harbinger of climate change and SLR, occurred in the

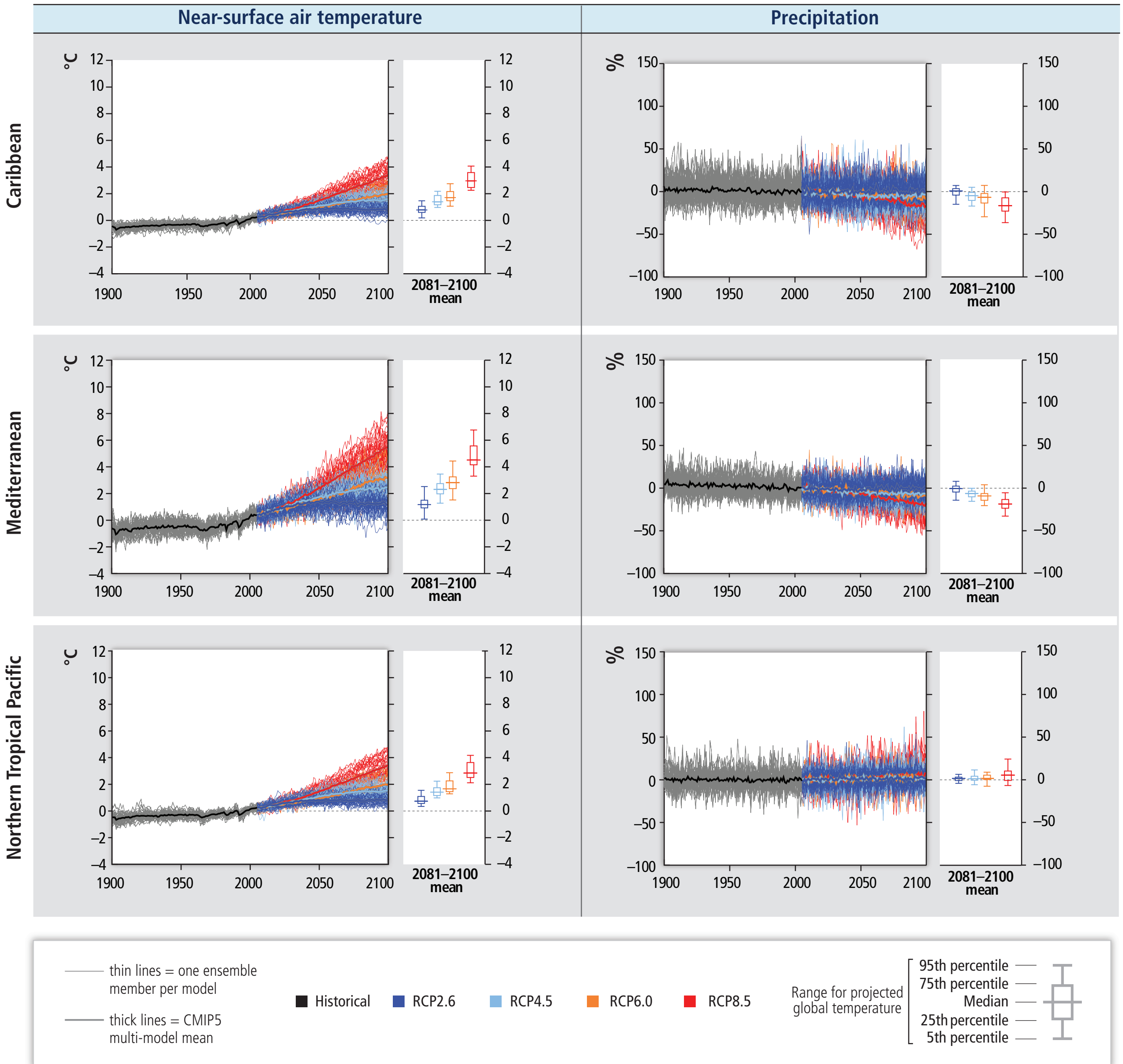
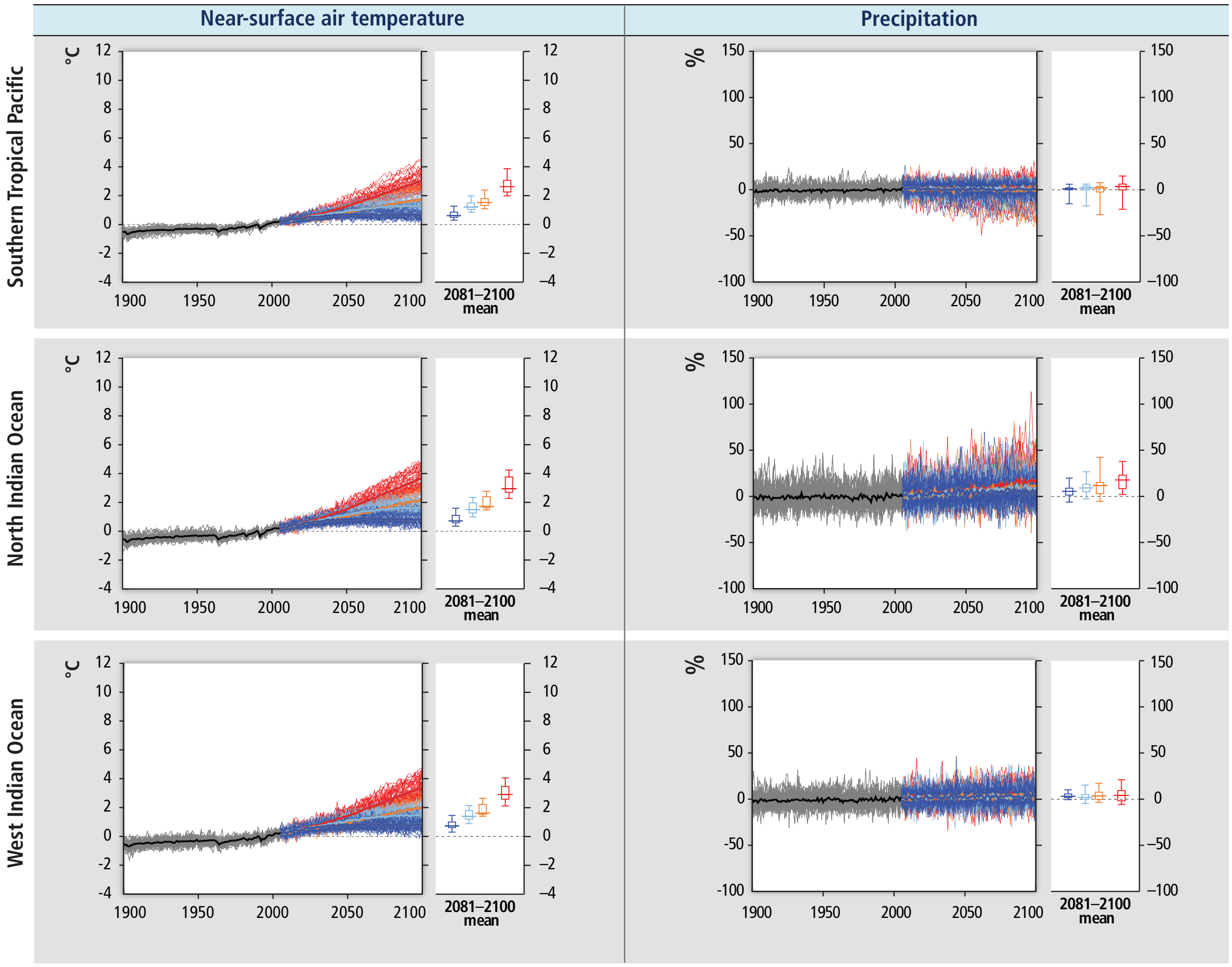


Figure 29-3 | Time series of Representative Concentration Pathway (RCP) scenarios annual projected temperature and precipitation change relative to 1986–2005 for six small islands regions (using regions defined in WGI AR5 Annex 1: Atlas of Global and Regional Climate Projections). Thin lines denote one ensemble member per model, and thick lines the Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model mean. On the righthand side, the 5th, 25th, 50th (median), 75th, and 95th percentiles of the distribution of 20-year mean changes are given for 2081–2100 in the four RCP scenarios. Note that the model ensemble averages in the figure are for grid points over wide areas and encompass many different climate change signals.

Continued next page →

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Figure 29-3 (continued)



Maldives in April 1987 when long period swells originating from the Southern Ocean some 6000 km away caused major flooding, damage to property, destruction of sea defenses, and erosion of reclaimed land and islands (Harangozo, 1992). The Maldives and several other island groups in the Indian Ocean have been subject to similar ocean swell events more recently, most notably in May 2007 (Maldives Department of Meteorology, 2007).

In the Caribbean, northerly swells affecting the coasts of islands have been recognized as a significant coastal hazard since the 1950s (Donn and McGuinness, 1959). They cause considerable seasonal damage to beaches, marine ecosystems, and coastal infrastructure throughout the region (Bush et al., 2009; Cambers, 2009). These high-energy events manifest themselves as long period high-amplitude waves that occur during the Northern Hemisphere winter and often impact the normally sheltered, low-energy leeward coasts of the islands. Such swells have even reached the shores of Guyana on the South American mainland as illustrated by a swell event in October 2005 that caused widespread flooding and overtopping and destruction of sea defenses (van Ledden et al., 2009).

Distant origin swells differ from the "normal" wave climate conditions experienced in the Caribbean, particularly with respect to direction of wave approach, wave height, and periodicity and in their morphological impact (Cooper et al., 2013). Swells of similar origin and characteristics also occur in the Pacific (Fletcher et al., 2008; Keener et al., 2012). These events frequently occur in the Hawaiian Islands, where there is evidence of damage to coral growth by swell from the north Pacific, especially during years with a strong El Niño signal (Fletcher et al., 2008).

Hoeke et al. (2013) describe inundation from mid- to high-latitude north and south Pacific waves respectively at Majuro (Marshall Islands) in November and December 1979 and along the Coral Coast (Fiji) in May 2011. They also describe in detail an inundation event in December 2008 that was widespread throughout the western and central Pacific and resulted in waves surging across low-lying islands causing severe damage to housing and infrastructure and key natural resources that affected about 100,000 people across the region. The proximate cause of this event was swell generated in mid-latitudes of the North Pacific Ocean, more than 4000 km from the farthest affected island (Hoeke et al., 2013).

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Whereas the origin of the long period ocean swells that impact small islands in the tropical regions come from the mid- and high latitudes in the Pacific, Indian, and Atlantic Oceans, there are also instances of unusually large waves generated from tropical cyclones that spread into the mid- and high latitudes. One example occurred during 1999 when tide gauges at Ascension and St. Helena Islands in the central south Atlantic recorded unusually large deep-ocean swell generated from distant Hurricane Irene (Vassie et al., 2004). The impacts of increasing incidence or severity of storms or cyclones is generally considered from the perspective of direct landfall of such systems, whereas all of these instances serve to show "the potential importance of swells to communities on distant, low-lying coasts, particularly if the climatology of swells is modified under future climate change" (Vassie et al., 2004, p. 1095). From the perspective of those islands that suffer damage from this coastal hazard on an annual basis, this is an area that warrants further investigation. Projected changes in global wind-wave climate to 2070–2100, compared to a base period 1979–2009, show considerable regional and seasonal differences with both decreases and increases in annual mean significant wave height. Of particular relevance in the present context is the projected increase in wave activity in the Southern Ocean, which influences a large portion of the global ocean as swell waves propagate northward into the Pacific, Indian, and Atlantic Oceans (Hemer et al., 2013).

Deep ocean swell waves and elevated sea levels resulting from ETCs are examples of inter-regional transboundary processes; locally generated tropical cyclones (TCs) provide examples of intra-regional transboundary processes. Whereas hurricane force winds, heavy rainfall, and turbulent seas associated with TCs can cause massive damage to both land and coastal systems in tropical small islands, the impacts of sea waves and inundation associated with far distant ETCs are limited to the coastal margins. Nevertheless both storm types result in a range of impacts covering island morphology, natural and ecological systems, island economies, settlements, and human well-being (see Figure 29-4).

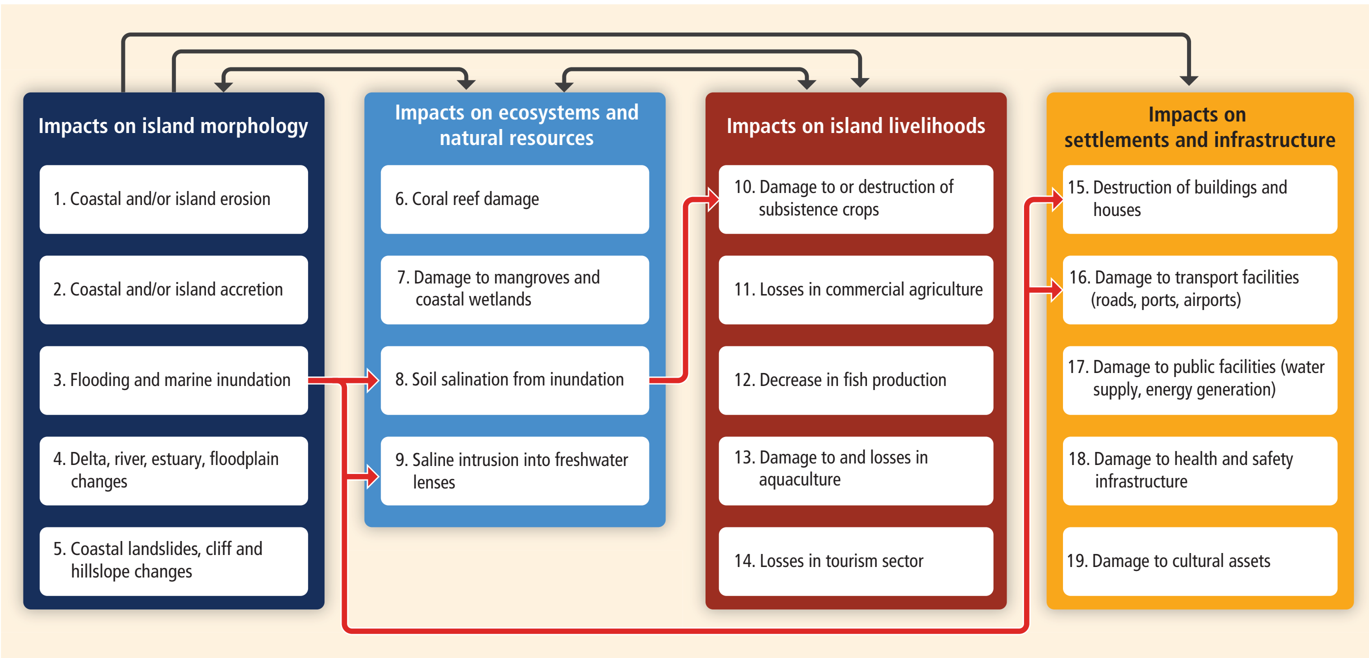


Figure 29-4 | Tropical and extratropical cyclone (ETC) impacts on the coasts of small islands. Four types of impacts are distinguished here, with black arrows showing the connections between them, based on the existing literature. An example of the chain of impacts associated with two ETCs centered to the east of Japan is illustrated by the red arrows. Swell waves generated by these events in December 2008 reached islands in the southwest Pacific and caused extensive flooding (3) that impacted soil quality (8) and freshwater resources (9), and damaged crops (10), buildings (15), and transport facilities (16) in the region (example based on Hoeke et al., 2013).

Examples of tropical cyclone impacts on small island coasts (with reference):
1. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 2. Taveuni, Fiji, March 2010 (Etienne and Terry, 2012); 3. Cook Islands (de Scally, 2008); Society and Autral Islands, French Polynesia, February 2010 (Etienne, 2012); 4. Viti Levu, Fiji, March 1997 (Terry et al., 2002); 5. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 6. Curacao, Bonaire, Netherlands Antilles, November 1999 (Scheffers and Scheffers, 2006); Hawaiian Islands (Fletcher et al., 2008); 7. Bay Islands, Honduras, October 1998 (Cahoon et al., 2003); 8. Marshall Islands, June 1905 (Spennemann, 1996); 9. Pukapuka atoll, Cook Islands, February 2005 (Terry and Falkland, 2010); 10. Vanuatu, February 2004 (Richmond and Sovacool, 2012); 11. 12. 13. Tuamotu Islands, French Polynesia, 1982–1983 (Dupon, 1987); 14. Grenada, September 2004 (OECS, 2004); 15. Grenada, September 2004 (OECS, 2004); Tubuai, Austral Islands, French Polynesia, February 2010 (Etienne, 2012); 16. Vanuatu, February 2004 (Richmond and Sovacool, 2012); Guadeloupe Island, October 2008 (Dorville and Zahibo, 2010); 17. Bora Bora, Raiatea, Maupiti, Tahaa, Huahine, Society Islands, February 2010 (Etienne, 2012); 18. Vanuatu, February 2004 (Richmond and Sovacool, 2012); 19. Tuamotu, French Polynesia, 1982–1983 (Dupon, 1987).

Examples of ETC impacts on small island coasts (with reference):
1. Maldives, April 1987 (Harangozo, 1992); 2. Maldives, January 1955 (Maniku, 1990); 3. Maldives, April 1987 (Harangozo, 1992); 9. Solomon Islands, December 2008 (Hoeke et al., 2013); 10. Chuck, Pohnpei, Kosrae, Federated States of Micronesia, December 2008 (Hoeke et al., 2013); 15. Majuro, Marshall Islands, November 1979 (Hoeke et al., 2013); 16. Coral Coast, Viti Levu, Fiji, May 2011 (Hoeke et al., 2013); 17. Majuro, Kwajalein, Arno, Marshall Islands, December 2008 (Hoeke et al., 2013); 18. Bismark Archipelago, Papua New Guinea, December 2008 (Hoeke et al., 2013).

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

29.5.2. Transcontinental Dust Clouds and Their Impact

The transport of airborne Saharan dust across the Atlantic and into the Caribbean has engaged the attention of researchers for some time. The resulting dust clouds are known to carry pollen, microbes, insects, bacteria, fungal spores, and various chemicals and pesticides (Prospero et al., 2005; Garrison et al., 2006; Middleton et al., 2008; Monteil, 2008; López-Villarrubia et al., 2010). During major events, dust concentrations can exceed 100 µg m^{-3} (Prospero, 2006). Independent studies using different methodologies have all found a strong positive correlation between dust levels in the Caribbean and periods of drought in the Sahara, while concentrations show a marked decrease during periods of higher rainfall. Consequently, it is argued that higher dust emissions due to increasing aridity in the Sahel and other arid areas could enhance climate change effects over large areas, including the eastern Caribbean and the Mediterranean (Prospero and Lamb, 2003). Similar findings have been reported at Cape Verde where dust emission levels were found to be a factor of nine lower during the decade of the 1950s when rainfall was at or above normal, compared to the 1980s, a period of intense drought in the Sahel region (Nicoll et al., 2011). Dust from the Sahara has also reached the eastern Mediterranean (e.g., Santese et al., 2010) whilst dust from Asia has been transported across the Pacific and Atlantic Oceans and around the world (Uno et al., 2009).

There is also evidence that the transboundary movement of Saharan dust into the island regions of the Caribbean, Pacific, and Mediterranean is associated with various human health problems (Griffin, 2007) including asthma admissions in the Caribbean (Monteil, 2008; Prospero et al., 2008; Monteil and Antoine, 2009) and cardiovascular morbidity in Cyprus in the Mediterranean (Middleton et al., 2008), and is found to be a risk factor in respiratory and obstructive pulmonary disease in the Cape Verde islands (Martins et al., 2009). These findings underscore the need for further research into the link among climate change, airborne aerosols, and human health in localities such as oceanic islands far distant from the continental source of the particulates.

29.5.3. Movement and Impact of Introduced and Invasive Species across Boundaries

Invasive species are colonizer species that establish populations outside their normal distribution ranges. The spread of invasive alien species is regarded as a significant transboundary threat to the health of biodiversity and ecosystems, and has emerged as a major factor in species decline, extinction, and loss of biodiversity goods and services worldwide. This is particularly true of islands, where both endemicity and vulnerability to introduced species tend to be high (Reaser et al., 2007; Westphal et al., 2008; Kenis et al., 2009; Rocha et al., 2009; Kueffer et al., 2010). The extent to which alien invasive species successfully establish themselves at new locations in a changing climate will be dependent on many variables, but non-climate factors such as ease of access to migration pathways, suitability of the destination, ability to compete and adapt to new environments, and susceptibility to invasion of host ecosystems are deemed to be critical. This is borne out, for example, by Le Roux et al. (2008), who studied the effect of the invasive weed *Miconia calvescens* in New Caledonia, Society Islands, and Marquesas Islands; by Gillespie et al. (2008) in an analysis of the spread of *Leucaena leucocephala*, *Miconia calvescens*, *Psidium* sp., and *Schinus terebinthifolius* in the Hawaiian Islands; and by Christenhusz and Toivonen (2008), who showed the potential for rapid spread and establishment of the oriental vessel fern, *Angiopteris evecta*, from the South Pacific throughout the tropics. Mutualism between an invasive ant and locally honeydew-producing insects has been strongly associated with damage to the native and functionally important tree species *Pisonia grandis* on Cousine Island, Seychelles (Gaigher et al., 2011).

While invasive alien species constitute a major threat to biodiversity in small islands, the removal of such species can result in recovery and return of species richness. This has been demonstrated in Mauritius by Baider and Florens (2011), where some forested areas were weeded of alien plants and after a decade the forest had recovered close to its initial condition. They concluded, given the severity of alien plant invasion in Mauritius, that their example can "be seen as a relevant model for a whole swath of other island nations and territories around the world particularly in the Pacific and Indian Oceans" (Baider and Florens, 2011, p. 2645).

The movement of aquatic and terrestrial invasive fauna within and across regions will almost certainly exacerbate the threat posed by climate change in island regions, and could impose significant environmental, economic, and social costs. Recent research has shown that the invasion of the Caribbean Sea by the Indo-Pacific lionfish (*Pterois volitans*), a highly efficient and successful predator, is a major contributor to observed increases in algal dominance in coral and sponge communities in the Bahamas and elsewhere in the region. The consequential damage to these ecosystems has been attributed to a significant decline in herbivores due to predation by lionfish (Albins and Hixon, 2008; Schofield, 2010; Green et al., 2011; Lesser and Slattery, 2011). Although there is no evidence that the lionfish invasion is climate-related, the concern is that when combined with preexisting stress factors the natural resilience of Caribbean reef communities will decrease (Green et al., 2012; Albins and Hixon, 2013), making them more susceptible to climate change effects such as bleaching. Englund (2008) has documented the negative effects of invasive species on native aquatic insects on Hawaii and French Polynesia, and their potential role in the extirpation of native aquatic invertebrates in the Pacific. Similarly, there is evidence that on the island of Oahu introduced slugs appear to be "skewing species abundance in favour of certain non-native and native plants," by altering the "rank order of seedling survival rates," thereby undermining the ability of preferred species (e.g., the endangered *C. superba*) to compete effectively (Joe and Daehler, 2008, p. 253).

29.5.4. Spread of Aquatic Pathogens within Island Regions

The mass mortality of the black sea urchin, *Diadema antillarum*, in the Caribbean basin during the early 1980s demonstrates the ease with which ecological threats in one part of a region can be disseminated to other jurisdictions thousands of kilometers away. The die-off was first observed in the waters off Panama around January 1983, and within 13 months the disease epidemic had spread rapidly through the Caribbean Sea, affecting practically all island reefs, as far away as Tobago some 2000 km to the south and Bermuda some 4000 km to the east. The diadema population in the wider Caribbean declined by more

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

than 93% as a consequence of this single episode (Lessios, 1988, 1995) As *D. antillarum* is one of the principal grazers that removes macroalgae from reefs and thus promotes juvenile coral recruitment, the collateral damage was severe, as the region's corals suffered from high morbidity and mortality for decades thereafter (Carpenter and Edmunds, 2006; Idjadi et al., 2010).

There are other climate-sensitive diseases such as yellow, white, and black band; white plague; and white pox that travel across national boundaries and infect coral reefs directly. This is variously supported by examples from the Indo-Pacific and Caribbean relating to the role of bacterial infections in white syndrome and yellow band disease (Piskorska et al., 2007; Cervino et al., 2008); the impact of microbial pathogens as stressors on benthic communities in the Mediterranean associated with warming seawater (Danovaro et al., 2009); and an increasing evidence of white, yellow, and black band disease associated with Caribbean and Atlantic reefs (Brandt and McManus, 2009; Miller, J. et al., 2009; Rosenberg et al., 2009; Weil and Croquer, 2009; Weil and Rogers, 2011).

29.5.5. Transboundary Movements and Human Health

For island communities the transboundary implications of existing and future human health challenges are projected to increase in a changing climate. For instance, the aggressive spread of the invasive giant African snail, *Achatina fulica*, throughout the Caribbean, Indo-Pacific Islands, and Hawaii is not only assessed to be a severe threat to native snails and other fauna (e.g., native gastropods), flora, and crop agriculture, but is also identified as a vector for certain human diseases such as meningitis (Reaser et al., 2007; Meyer et al., 2008; Thiengo et al., 2010).

Like other aquatic pathogens, ciguatoxins that cause ciguatera fish poisoning may be readily dispersed by currents across and within boundaries in tropical and subtropical waters. Ciguatoxins are known to be highly temperature-sensitive and may flourish when certain seawater temperature thresholds are reached, as has been noted in the South Pacific (Llewellyn, 2010), Cook Islands (Rongo and van Woesik, 2011), Kiribati (Chan et al., 2011), the Caribbean and Atlantic (Otero et al., 2010; Tester et al., 2010), and Mediterranean (Aligizaki and Nikolaidis, 2008; see also Section 29.3.3.2).

29.6. Adaptation and Management of Risks

Islands face risks from both climate-related hazards that have occurred for centuries, as well as new risks from climate change. There have been extensive studies of the risks associated with past climate-related hazards and adaptations to these, such as tropical cyclones, drought, and disease, and their attendant impacts on human health, tourism, fisheries, and other areas (Bijlsma et al., 1996; Cronk 1997; Solomon and Forbes 1999; Pelling and Uitto 2001). There have also been many studies that have used a variety of vulnerability, risk, and adaptation assessment methods particularly in the Pacific that have recently been summarized by Hay et al. (2013). But for most islands, there is very little published literature documenting the probability, frequency, severity, or consequences of climate change risks such as SLR, ocean acidification, and salinization of freshwater resources—or associated adaptation measures. Projections of future climate change risks are limited by the lack of model skill in projecting the climatic variables that matter to small islands, notably tropical cyclone frequency and intensity, wind speed and direction, precipitation, sea level, ocean temperature, and ocean acidification (Brown et al., 2013b); inadequate projections of regional sea levels (Willis and Church, 2012); and a lack of long-term baseline monitoring of changes in climatic risk, or to ground-truth models (Voccia, 2012), such as risk of saline intrusion, risk of invasive species, risk of biodiversity loss, or risk of large ocean waves. In their absence, qualitative studies have documented perceptions of change in current risks (Fazey et al., 2011; Lata and Nunn, 2012), reviewed effective coping mechanisms for current stressors (Bunce et al., 2009; Campbell et al., 2011) and have considered future scenarios of change (Weir and Virani, 2011). These studies highlight that change is occurring, but they do not quantify the probability, speed, scale, or distribution of future climate risks. The lack of quantitative published assessments of climate risk for many small islands means that future adaptation decisions have to rely on analogs of responses to past and present weather extremes and climate variability, or assumed/hypothesized impacts of

Table 29-3 | Types of island in the Pacific region and implications for hydro-meteorological hazards (after Campbell, 2009).

Island type and size		Island elevation, slope, rainfall	Implications for hazard
Continental	• Large • High biodiversity • Well-developed soils	• High elevations • River flood plains • Orographic rainfall	River flooding more likely to be a problem than in other island types. In Papua New Guinea, high elevations expose areas to frost (extreme during El Niño).
Volcanic high islands	• Relatively small land area • Barrier reefs • Different stages of erosion	• Steep slopes • Less well-developed river systems • Orographic rainfall	Because of size, few areas are not exposed to tropical cyclones. Streams and rivers are subject to flash flooding. Barrier reefs may ameliorate storm surge.
Atolls	• Very small land area • Small islets surround a lagoon • Larger islets on windward side • Shore platform on windward side • No or minimal soil	• Very low elevations • Convectional rainfall • No surface (fresh) water • Ghyben–Herzberg (freshwater) lens	Exposed to storm surge, "king" tides, and high waves. Narrow resource base. Exposed to freshwater shortages and drought. Water problems may lead to health hazards.
Raised limestone islands	• Concave inner basin • Narrow coastal plains • No or minimal soil	• Steep outer slopes • Sharp karst topography • No surface water	Depending on height, may be exposed to storm surge. Exposed to freshwater shortages and drought. Water problems may lead to health hazards.

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

climate change based on island type (see Table 29-3). Differences in island type and differences in exposure to climate forcing and hazards vary with island form, providing a framework for consideration of vulnerability and adaptation strategies. Place-based understanding of island landscapes and of processes operating on individual islands is critical (Forbes et al., 2013).

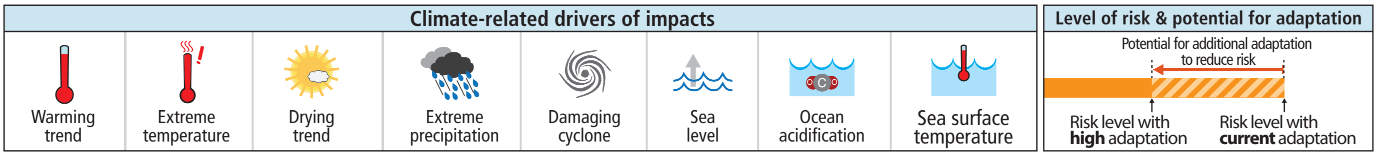
29.6.1. Addressing Current Vulnerabilities on Small Islands

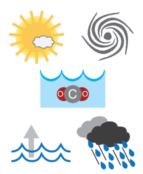
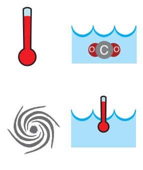
Islands are heterogeneous in geomorphology, culture, ecosystems, populations, and hence also in their vulnerability to climate change. Vulnerabilities and adaptation needs are as diverse as the variety of islands between regions and even within nation states (e.g., in Solomon Islands; Rasmussen et al., 2011), often with little climate adaptation occurring in peripheral islands, for example, in parts of the Pacific (Nunn et al., 2013). Quantitative comparison of vulnerability is difficult owing to the paucity of vulnerability indicators. Generic indices of national level vulnerability continue to emerge (Cardona, 2007) but only a minority are focused on small islands (e.g., Blancard and Hoarau, 2013). The island-specific indicators that exist often suffer from lack of data (Peduzzi et al., 2009; Hughes et al., 2012), use indicators that are not relevant in all islands (Barnett and Campbell, 2010), or use data of limited quality for islands, such as SLR (as used in Wheeler, 2011). As a result indicators of vulnerability for small islands often misrepresent actual vulnerability. Recent moves toward participatory approaches that link scientific knowledge with local visions of vulnerability (see Park et al., 2012) offer an important way forward to understanding island vulnerability in the absence of certainty in model-based scenarios.

Island vulnerability is often a function of four key stressors: physical, socioeconomic, socio-ecological, and climate-induced, whose reinforcing mechanisms are important in determining the magnitude of impacts. Geophysical characteristics of islands (see Table 29-2; Figure 29-1) create inherent physical vulnerabilities. Thus, for example the Azores (Portugal) face seismic, landslide, and tsunami risks (Coutinho et al., 2009). Socioeconomic vulnerabilities are related to ongoing challenges of managing urbanization, pollution, and sanitation, both in small island states and non-sovereign islands as highlighted by Storey and Hunter (2010) in Kiribati, López-Marrero and Yarnal (2010) in Puerto Rico, and in Mayotte, France (Le Masson and Kelman, 2011). Socio-ecological stresses, such as habitat loss and degradation, invasive species (described in Sax and Gaines, 2008), overexploitation, pollution, human encroachment, and disease can harm biodiversity (Kingsford et al., 2009; Caujape-Castells et al., 2010), and reduce the ability of socio-ecological systems to bounce back after shocks.

To understand climate vulnerability on islands, it is necessary to assess all of these dimensions of vulnerability (Rasmussen et al., 2011). For example, with individual ecosystems such as coral reef ecosystems, those already under stress from non-climate factors are more at risk from climate change than those that are unstressed (Hughes et al., 2003; Maina et al., 2011). Evidence is starting to emerge that shows the same applies at the island scale. In Majuro atoll (Marshall Islands), 34 to 37 years of aerial photography shows that socio-ecological stress is exacerbating shoreline change associated with SLR, especially on the lagoon side of islands (Ford, 2012; see also Section 29.3.1.1). Islands faced with multiple stressors can therefore be assumed to be more at risk from climate impacts.

Table 29-4 | Selected key risks and potential for adaptation for small islands from the present day to the long term.



Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Loss of livelihoods, coastal settlements, infrastructure, ecosystem services, and economic stability (*high confidence*) [29.6, 29.8, Figure 29-4]	• Significant potential exists for adaptation in islands, but additional external resources and technologies will enhance response. • Maintenance and enhancement of ecosystem functions and services and of water and food security • Efficacy of traditional community coping strategies is expected to be substantially reduced in the future.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low / Medium / Very high
Decline and possible loss of coral reef ecosystems in small islands through thermal stress (*high confidence*) [29.3.1.2]	Limited coral reef adaptation responses; however, minimizing the negative impact of anthropogenic stresses (ie: water quality change, destructive fishing practices) may increase resilience.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low / Medium / Very high
The interaction of rising global mean sea level in the 21st century with high-water-level events will threaten low-lying coastal areas (*high confidence*) [29.4, Table 29-1; WGI AR5 13.5, Table 13.5]	• High ratio of coastal area to land mass will make adaptation a significant financial and resource challenge for islands. • Adaptation options include maintenance and restoration of coastal landforms and ecosystems, improved management of soils and freshwater resources, and appropriate building codes and settlement patterns.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low / Medium / Very high

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Despite the limited ability of continental scale models to predict climate risks for specific islands, or the limited capacity of island vulnerability indicators, scenario based damage assessments can be undertaken. Storm surge risks have been effectively modeled for the Andaman and Nicobar Islands (Kumar et al., 2008). Rainfall-induced landslide risk maps have been produced for both Jamaica (Miller, S. et al., 2009) and the Chuuk Islands (Federated States of Micronesia; Harp et al., 2009). However, the probability of change in frequency and severity of extreme rainfall events and storm surges remains poorly understood for most small islands. Other risks, such as the climate change-driven health risks from the spread of infectious disease, loss of settlements and infrastructure, and decline of ecosystems that affect island economies, livelihoods, and human well-being also remain under-researched. Nevertheless, it is possible to consider these risks along with the threat of rising sea level and suggest a range of contemporary and future adaptation issues and prospects for small islands (see Table 29-4).

29.6.2. Practical Experiences of Adaptation on Small Islands

There is disagreement about whether islands and islanders have successfully adapted to past weather variability and climate change. Nunn (2007) argues that past climate changes have had a "crisis effect" on prehistoric societies in much of the Pacific Basin. In contrast, a variety of studies argue that past experiences of hydro-meteorological extreme events have enabled islands to become resilient to weather extremes (Barnett, 2001). Resilience appears to come from both a belief in their own capacity (Adger and Brown, 2009; Kuruppu and Liverman, 2011), and a familiarity with their environment and understanding of what is needed to adapt (Tompkins et al., 2009; Le Masson and Kelman, 2011). For example, compared to communities in the larger countries of Madagascar, Tanzania, and Kenya, the Indian Ocean islands (Seychelles and Mauritius) were found to have: comparatively high capacity to anticipate change and prepare strategies; self-awareness of human impact on environment; willingness to change occupation; livelihood diversity; social capital; material assets; and access to technology and infrastructure—all of which produced high adaptive capacity (Cinner et al., 2012). Despite this resilience, islands are assumed to be generically vulnerable to long term future climate change (Myers, 2002; Parks and Roberts, 2006).

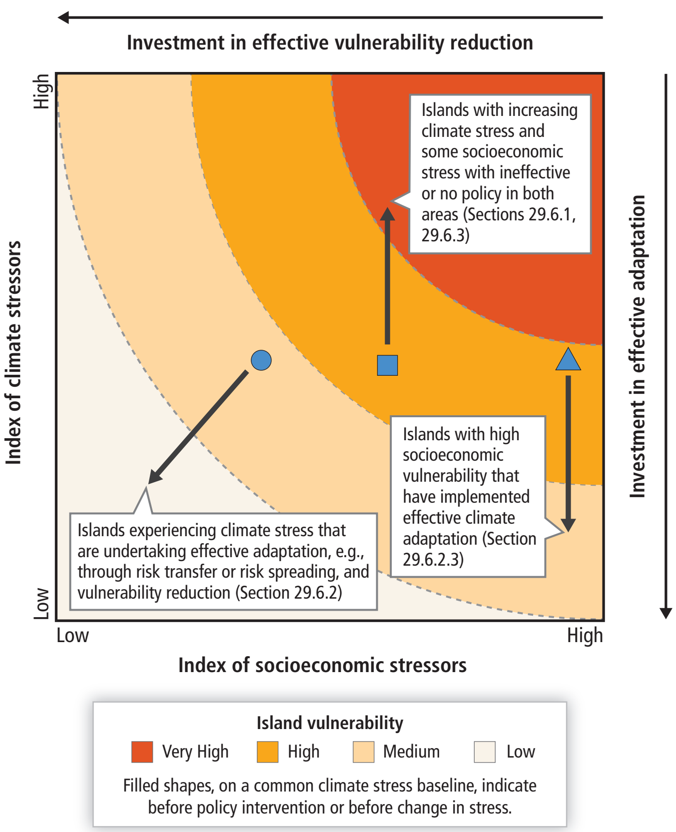


Figure 29-5 | The impact of alternative climate change adaptation actions or policies.

There are many ways in which *in situ* climate adaptation can be undertaken: reducing socioeconomic vulnerabilities, building adaptive capacity, enhancing disaster risk reduction, or building longer term climate resilience (e.g., see McGray et al., 2007; Eakin et al., 2009). Figure 29-5 highlights the implications of the various options. Not all adaptations are equally appropriate in all contexts. Understanding the baseline conditions and stresses (both climate and other) are important in understanding which climate change adaptation option will generate the greatest benefits. On small islands where resources are often limited, recognizing the starting point for action is critical to maximizing the benefits from adaptation. The following section considers the benefits of pursuing the various options.

29.6.2.1. Building Adaptive Capacity with Traditional Knowledge, Technologies, and Skills on Small Islands

As in previous IPCC assessments, there is continuing strong support for the incorporation of indigenous knowledge into adaptation planning. However, this is moderated by the recognition that current practices alone may not be adequate to cope with future climate extremes or trend changes. The ability of a small island population to deal with current climate risks may be positively correlated with the ability to adapt to future climate change, but evidence confirming this remains limited (such as Lefale, 2010). Consequently, this section focuses on evidence for adaptive capacity that reduces vulnerability to existing stressors, enables adaptation to current stresses, and supports current disaster risk management.

Traditional knowledge has proven to be useful in short-term weather forecasting (e.g., Lefale, 2010) although evidence is inconclusive on local capacity to observe long-term climate change (e.g., Hornidge and Scholtes, 2011). In Solomon Islands, Lauer and Aswani (2010) found mixed ability to detect change in spatial cover of seagrass meadows. In Jamaica, Gamble et al. (2010) reported a high level of agreement between farmers' perception of increasing drought incidence and statistical analysis of precipitation and vegetation data for the area. In this case farmers' perceptions clearly validated the observational data and vice versa. Despite some claims that vulnerability reduction in indigenous communities in small islands may be best tackled by combining indigenous and Western knowledge in a culturally compatible and sustainable manner (Mercer et al., 2007), given the small number of studies in this area, there is not sufficient evidence to determine the

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

effectiveness and limits to the use of traditional methods of weather forecasting under climate change on small islands.

Traditional technologies and skills can be effective for current disaster risk management but there is currently a lack of supporting evidence to suggest that they will be equally appropriate under changing cultural conditions and future climate changes on islands. Campbell (2009) identified that traditional disaster reduction measures used in Pacific islands focused around maintaining food security, building community cooperation, and protecting settlements and inhabitants. Examples of actions to maintain food security include: the production and storage of food surpluses, such as yam and breadfruit buried in leaf-lined pits to ferment; high levels of agricultural diversity to minimize specific damage to any one crop; and the growth of robust famine crops, unused in times of plenty that could be used in emergencies (Campbell, 2009). Two discrete studies from Solomon Islands highlight the importance of traditional patterns of social organization within communities to support food security under social and environmental change (Reenberg et al., 2008; Mertz et al., 2010). In both studies the strategy of relying on traditional systems of organization for farming and land use management have been shown to work effectively—largely as there has been little cultural and demographic change. Nonetheless there are physical and cultural limits to traditional disaster risk management. In relation to the ability to store surplus production on atoll islands, on Rongelap in the Marshall Islands, surpluses are avoided, or are redistributed to support community bonds (Bridges and McClatchey, 2009). Further, traditional approaches that Pacific island communities have used for survival for millennia (such as building elevated settlements and resilient structures, and working collectively) have been abandoned or forgotten due to processes of globalization, colonialism, and development (Campbell, 2009). Ongoing processes of rapid urbanization and loss of language and tradition suggest that traditional approaches may not always be efficacious in longer term adaptation.

Traditional construction methods have long been identified across the Pacific as a means of reducing vulnerability to tropical cyclones and floods in rural areas. In Solomon Islands traditional practices include: elevating concrete floors on Ontong Java to keep floors dry during heavy rainfall events; building low, aerodynamic houses with sago palm leaves as roofing material on Tikopia as preparedness for tropical cyclones; and in Bellona local perceptions are that houses constructed from modern materials and practices are more easily destroyed by tropical cyclones, implying that traditional construction methods are perceived to be more resilient in the face of extreme weather (Rasmussen et al., 2009). In parallel, Campbell (2009) documents the characteristics of traditional building styles (in Fiji, Samoa, and Tonga) where relatively steep hipped roofs, well bound connections and joints, and airtight spaces with few windows or doors offer some degree of wind resistance. Traditional building measures can also reduce damages associated with earthquakes, as evidenced in Haiti (Audefroy, 2011). By reducing damage caused by other stresses (such as earthquakes), adaptive capacity is more likely to be maintained. The quality of home construction is critical to its wind resistance. If inadequately detailed, home construction will fail irrespective of method. Although some traditional measures could be challenged as potentially risky—for example, using palm leaves, rather than metal roofs as a preparation for tropical cyclone impacts—the documentation of traditional approaches, with an evaluation of their effectiveness remains urgently needed. Squatter settlements in urban areas, especially on steep hillsides in the Caribbean, often use poor construction practices frequently driven by poverty and inadequate building code enforcement (Prevatt et al., 2010).

Traditional systems appear less effective when multiple civilization-nature stresses are introduced. For example, in Reunion and Mayotte, population growth, and consequent rises in land and house prices, have led low-income families to settle closer to hazardous slopes that are prone to landslides and to river banks which are prone to flooding (Le Masson and Kelman, 2011). Traditional belief systems can also limit adaptive capacity. Thus, for example, in two Fijian villages, approximately half of survey respondents identified divine will as the cause of climate change (Lata and Nunn, 2012). These findings reinforce earlier studies in Tuvalu (Mortreux and Barnett, 2009), and more widely across the Pacific (Barnett and Campbell, 2010). The importance of taking into account local interests and traditional knowledge in adaptation in small islands is emphasized by Kelman and West (2009) and McNamara and Westoby (2011), yet evidence does not yet exist that reveals the limits to such knowledge, such as in the context of rapid socio-ecological change, or the impact of belief systems on adaptive capacity.

While there is clear evidence that traditional knowledge networks, technologies, and skills can be used effectively to support adaptation in certain contexts, the limits to these tools are not well understood. To date research in the Pacific and Caribbean dominates small island climate change work. More detailed studies on small islands in the central and western Indian Ocean, the Mediterranean, and the central and eastern Atlantic would improve understanding on this topic.

29.6.2.2. Addressing Risks on Small Islands

Relative to other areas, small islands are disproportionately affected by current hydro-meteorological extreme events, both in terms of the percentage of the population affected and losses as a percentage of GDP (Anthoff et al., 2010; Table 29-5). Under climate change the risks of damage and associated losses are expected to continue to rise (Nicholls and Cazenave, 2010). Yet much of the existing literature on climate risk in small islands does not consider how to address high future risks, but instead focuses on managing present-day risks through risk transfer, risk spreading, or risk avoidance. Risk transfer is largely undertaken through insurance; risk spreading through access to and use of common property resources, livelihood diversification, or mutual support through networks (see Section 29.6.2.3); and risk avoidance through structural engineering measures or migration (see Section 29.6.2.4).

Risk transfer through insurance markets has had limited uptake in small islands, as insurance markets do not function as effectively as they do in larger locations, in part owing to a small demand for the insurance products (Heger et al., 2008). In the case of insurance for farmers, researchers found that a lack of demand for insurance products (in their study countries: Grenada, Jamaica, Fiji, and Vanuatu) meant an under-supply of customized food insurance products, which in turn contributed to a lack of demand for insurance (Angelucci and Conforti, 2010). Alternatives exist such as index-based schemes that provide payouts based on the crossing of a physical threshold, for example, when rainfall

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Table 29-5 | Top ten countries in the Asia–Pacific region based on absolute and relative physical exposure to storms and impact on GDP (between 1998 and 2009; after Tables 1.10 and 1.11 of ESCAP and UNISDR, 2010).

Rank	Absolute exposure (millions affected)	Relative exposure (% of population affected)	Absolute GDP loss (US$ billions)	Loss (% of GDP)
1	Japan (30.9)	Northern Mariana Islands (58.2)	Japan (1,226.7)	Northern Mariana Islands (59.4)
2	Philippines (12.1)	Niue (25.4)	Republic of Korea (35.6)	Vanuatu (27.1)
3	China (11.1)	Japan (24.2)	China (28.5)	Niue (24.9)
4	India (10.7)	Philippines (23.6)	Philippines (24.3)	Fiji (24.1)
5	Bangladesh (7.5)	Fiji (23.1)	Hong Kong (13.3)	Japan (23.9)
6	Republic of Korea (2.4)	Samoa (21.4)	India (8.0)	Philippines (23.9)
7	Myanmar (1.2)	New Caledonia (20.7)	Bangladesh (3.9)	New Caledonia (22.4)
8	Vietnam (0.8)	Vanuatu (18.3)	Northern Mariana Islands (1.5)	Samoa (19.2)
9	Hong Kong (0.4)	Tonga (18.1)	Australia (0.8)	Tonga (17.4)
10	Pakistan (0.3)	Cook Islands (10.5)	New Caledonia (0.7)	Bangladesh (5.9)

Note: Small islands are highlighted in yellow.

drops below a certain level, rather than on drought damage sustained (Linnerooth-Bayer and Mechler, 2009). The potential for index-based insurance for climate stressors on islands is under-researched and there remains limited evidence of the long-term effectiveness of index-based or pooled-risk insurance in supporting household level adaptation. Small island governments also face expensive climate risk insurance. The Caribbean Catastrophe Risk Insurance Facility (CCRIF), which has been operating since 2007, pools Caribbean-wide country-level risks into a central, more diversified risk portfolio—offering lower premiums for participating national governments (CCRIF, 2008). The potential for a similar scheme in the Pacific is being explored (ADB, 2009; Cummins and Mahul, 2009).

Risk can be spread socially, for example, through social networks and familial ties (see also Section 29.6.2.3), or ecologically, for example, by changing resource management approach. Social networks can be used to spread risk among households. In Fiji, after Tropical Cyclone Ami in 2003, households whose homes were not affected by the cyclone increased their fishing effort to support those whose homes were damaged (Takasaki, 2011)—mutual support formed a central pillar for community-based adaptation. In the case of natural systems, risks can be spread through enhancing representation of habitat types and replication of species, for example, through the creation of marine protected areas, around key refuges that protect a diversity of habitat, that cover an adequate proportion of the habitat and that protect critical areas such as nursery grounds and fish spawning aggregation areas (McLeod et al., 2009). Locally Managed Marine Areas—which involve the local community in the management and protection of their local marine environment—have proven to be effective in increasing biodiversity, and in reducing poverty in areas dependent on marine resources in several Pacific islands (Techera, 2008; Game et al., 2011). By creating a network of protected areas supported by local communities the risks associated with some forms of climate change can be spread and potentially reduced (Mills et al., 2010) although such initiatives may not preserve thermally sensitive corals in the face of rising SST.

Risk avoidance through engineered structures can reduce risk from some climate-related hazards (*medium evidence*, *medium agreement*). In Jamaica, recommendations to reduce rainfall-driven land surface movements resulting in landslides include: engineering structures such as soil nailing, gabion baskets (i.e., cages filled with rocks), rip rapped surfaces (i.e., permanent cover with rock), and retaining walls together with engineered drainage systems (Miller, S. et al., 2009). Engineering principles to reduce residential damage from hurricanes have been identified, tested, and recommended for decades in the Caribbean. However, expected levels of success have often not been achieved owing to inadequate training of construction workers, minimal inspection of new buildings, and lack of enforcement of building code requirements (Prevatt et al., 2010). Some island states do not even have the technical or financial capacity to build effective shore protection structures, as highlighted by a recent assessment in south Tarawa, Kiribati (Duvat, 2013).

In addition, not all engineered structures are seen as effective risk avoidance mechanisms. In the Azores archipelago, a proliferation of permanent engineered structures along the coastline to prevent erosion have resulted in a loss of natural shoreline protection against wave erosion (Calado et al., 2011). In Barbados it is recognized that seawalls can protect human assets in areas prone to high levels of erosion; however, they can also cause sediment starvation in other areas, interfere with natural processes of habitat migration, and cause coastal squeeze, which may render them less desirable for long-term adaptation (Mycoo and Chadwick, 2012; see also Section 5.4.2.1). To reduce erosion risk an approach with less detrimental downstream effects that also supports tourism is beach nourishment. This is increasingly being recommended, for example, in the Caribbean (Mycoo and Chadwick, 2012), the Mediterranean (Anagnostou et al., 2011), and western Indian Ocean (Duvat, 2009). Beach nourishment, however, is not without its challenges, as requirements such as site-specific oceanographic and wave climate data, adequate sand resources, and critical engineering design skills may not be readily available in some small islands.

29.6.2.3. Working Collectively to Address Climate Impacts on Small Islands

More attention is being focused on the relevance and application of community-based adaptation (CBA) principles to island communities,

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

to facilitate adaptation planning and implementation (Warrick, 2009; Kelman et al., 2011) and to tackle rural poverty in resource-dependent communities (Techera, 2008). CBA research is focusing on empowerment that helps people to help themselves, for example, through marine catch monitoring (Breckwoldt and Seidel, 2012), while addressing local priorities and building on local knowledge and capacity. This approach to adaptation is being promoted as an appropriate strategy for small islands, as it is something done "with" rather than "to" communities (Warrick, 2009). Nonetheless externally driven programs to encourage community-level action have produced some evidence of effective adaptation. Both Limalevu et al. (2010) and Dumaru (2010) describe the outcomes of externally led pilot CBA projects (addressing water security and coastal management) implemented in villages across Fiji, notably more effective management of local water resources through capacity building; enhanced knowledge of climate change; and the establishment of mechanisms to facilitate greater access to technical and financial resources from outside the community. More long-term monitoring and evaluation of the effectiveness of community level action is needed.

Collaboration between stakeholders can lessen the occurrence of simple mistakes that can reduce the effectiveness of adaptation actions (*medium evidence*, *medium agreement*). Evidence from the eastern Caribbean suggests that adaptations taken by individual households to reduce landslide risk—building simple retaining walls—can be ineffective compared to community-level responses (Anderson et al., 2011). Landslide risk can be significantly reduced through better hillside drainage. In the eastern Caribbean, community groups, with input from engineers, have constructed these networks of drains to capture surface runoff, household roof water, and gray water. Case studies from Fiji and Samoa in which multi-stakeholder and multi-sector participatory approaches were used to help enhance resilience of local residents to the adverse impacts of disasters and climate change (Gero et al., 2011) further support this view. In the case of community-based disaster risk reduction (CBDRR), Pelling (2011) notes that buy-in from local and municipal governments is needed, as well as strong preexisting relationships founded on routine daily activities, to make CBDRR effective. Research from both Solomon Islands and the Cayman Islands reinforce the conclusion that drivers of community resilience to hazard maps closely onto factors driving successful governance of the commons, that is, community cohesion, effective leadership, and community buy-in to collective action (Tompkins et al., 2008; Schwarz et al., 2011). Where community organizations are operating in isolation, or where there is limited coordination and collaboration, community vulnerability is expected to increase (Ferdinand et al., 2012). Strong local networks, and trusting relationships between communities and government, appear to be key elements in adaptation, in terms of maintaining sustainable agriculture and in disaster risk management (*medium evidence*, *high agreement*).

All of these studies reinforce the earlier work of Barnett (2001), providing empirical evidence that supporting community-led approaches to disaster risk reduction and hazard management may contribute to greater community engagement with anticipatory adaptation. However, it is not yet possible to identify the extent to which climate resilience is either a coincidental benefit of island lifestyle and culture, or a purposeful approach, such as the community benefits gained from reciprocity among kinship groups (Campbell, 2009).

29.6.2.4. Addressing Long-Term Climate Impacts and Migration on Small Islands

SLR poses one of the most widely recognized climate change threats to low-lying coastal areas on islands (Section 29.3.1). However, long-term climate impacts depend on the type of island (see Figure 29-1) and the adaptation strategy adopted. Small island states have 16% of their land area in low elevation coastal areas (<10 m) as opposed to a global average of 2%, and the largest proportion of low-elevation coastal urban land area: 13% (along with Australia and New Zealand), in contrast to the global average of 8% (McGranahan et al., 2007). Statistics like these underpin the widely held view about small islands being "overwhelmed" by rising seas associated with SLR (Loughry and McAdam, 2008; Laczko and Aghazarm, 2009; Yamamoto and Esteban, 2010; Berringer, 2012; Dema, 2012; Gordon-Clark, 2012; Lazrus, 2012). Yet there remains *limited evidence* as to which regions (Caribbean, Pacific and Indian Oceans, West African islands) will experience the largest SLR (Willis and Church, 2012) and which islands will experience the worst climate impacts. Nicholls et al. (2011) have modeled impacts of 4°C warming, producing a 0.5 to 2.0 m SLR, to assess the impacts on land loss and migration. With no adaptation occurring, they estimate that this could produce displacement of between 1.2 and 2.2 million people from the Caribbean and Indian and Pacific Oceans. More research is needed to produce *robust agreement* on the impact of SLR on small islands, and on the range of adaptation strategies that could be appropriate for different island types under those scenarios. Research into the possible un-inhabitability of islands has to be undertaken sensitively to avoid short-term risks (i.e., to avoid depopulation and ultimately island abandonment) associated with a loss of confidence in an island's future (McNamara and Gibson, 2009; McLeman, 2011).

Owing to the high costs of adapting on islands, it has been suggested that there will be a need for migration (Biermann and Boas, 2010; Gemenne, 2011; Nicholls et al., 2011; Voccia 2012). Relocation and displacement are frequently cited as outcomes of SLR, salinization, and land loss on islands (Byravan and Rajan, 2006; Kolmannskog and Trebbi, 2010; see also Section 29.3.3.3). Climate stress is occurring at the same time as the growth in rural to urban migration. The latter is leading to squatter settlements that strain urban infrastructure—notably sewerage, waste management, transport, and electricity (Connell and Lea, 2002; Jones, 2005). Urban squatters on islands often live in highly exposed locations, lacking basic amenities, leaving them highly vulnerable to climate risks (Baker, 2012). However, a lack of research in this area makes it difficult to draw clear conclusions on the impact of climate change on the growing number of urban migrants in islands.

Recent examples of environmental stress-driven relocation and displacement provide contemporary analogs of climate-induced migration. Evidence of post-natural disaster migration has been documented in the Caribbean in relation to hurricanes (McLeman and Hunter, 2010) and in the Carteret Islands, Papua New Guinea, where during an exceptionally high inundation event in 2008 (see Section 29.5.1.1) islanders sought refuge on neighboring Bougainville Island (Jarvis, 2010). Drawing any strong conclusions from this literature is challenging, as there is little understanding of how to measure the effect of the environmental signal in migration patterns (Krishnamurthy, 2012; Afifi et al., 2013). Although the example of the Carteret Islands cannot be

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

described as evidence of adaptation to climate change, it suggests that under some extreme scenarios island communities may need to consider relocating in the future (Gemenne, 2011). In reality, financial and legal barriers are expected to inhibit significant levels of international environmentally induced migration in the Pacific (Barnett and Chamberlain, 2010).

29.6.3. Barriers and Limits to Adaptation in Small Island Settings

Since publication of the SAR in 1996, significant barriers to climate change adaptation strategies in island settings have been discussed in considerable detail. Barriers include inadequate access to financial, technological, and human resources; issues related to cultural and social acceptability of measures; constraints imposed by the existing political and legal framework; the emphasis on island development as opposed to sustainability; a tendency to focus on addressing short-term climate variability rather than long-term climate change; and community preferences for "hard" adaptation measures such as seawalls instead of "soft" measures such as beach nourishment (Sovacool, 2012). Heger et al. (2008) recognized that more diversified economies have more robust responses to climate stress, yet most small islands lack economies of scale in production, thus specializing in niche markets and developing monocultures (e.g., sugar or bananas). Non-sovereign island states face additional exogenous barriers to adaptation. For example, islands such as Réunion and Mayotte benefit from the provision of social services somewhat similar to what obtains in the Metropole, but not the level of enforcement of building codes and land use planning as in France (Le Masson and Kelman, 2011). Owing to their nature and complexity, these constraints will not be easily eliminated in the short term and will require ongoing attention if their impact is to be minimized over time. Exogenous factors such as the comparatively few assessments of social vulnerability to climate change, adaptation potential, or resilience for island communities (Barnett, 2010) limit current understanding. In part this is due to the particularities of islands—both their heterogeneity and their difference from mainland locations—as well as the limitations of climate models in delivering robust science for small islands. It remains the case that, 13 years after Nurse et al. (2001) noted that downscaled global climate models do not provide a complete or necessarily accurate picture of climate vulnerabilities on islands, there is still little climate impacts research that reflects local concerns and contexts (Barnett et al., 2008).

Although lack of access to adequate financial, technological and human resources is often cited as the most critical constraint, experience has shown that endogenous factors such as culture, ethics, knowledge, and attitudes to risk are important in constraining adaptation. Translating the word "climate" into Marshallese implies cosmos, nature, and culture as well as weather and climate (Rudiak-Gould, 2012). Such cultural misunderstandings can create both barriers to action and novel ways of engaging with climate change. The lack of local support (owing to encroachment on traditional lands) for the development of new infiltration galleries to augment freshwater supply on Tarawa atoll, Kiribati, highlights the importance of social acceptability (Moglia et al., 2008a,b). Such considerations have led to the conclusion that there is still much to be learned about the drivers of past adaptation and how "mainstreaming" into national programs and policies, widely acclaimed to be a virtually indispensable strategy, can practically be achieved (Mercer et al., 2007; Adger et al., 2009; Mertz et al., 2009).

Notwithstanding the extensive and ever-growing body of literature on the subject, there is still a relatively low level of awareness and understanding at the community level on many islands about the nature of the threat posed by climate change (Nunn, 2009). Even where the threat has been identified, it is often not considered an urgent issue, or a local priority, as exemplified in Malta (Akerlof et al., 2010) and Funafuti, Tuvalu (Mortreux and Barnett, 2009). Lack of awareness, knowledge, and understanding can function as an effective barrier to the implementation and ultimate success of adaptation programs. This is borne out in both Fiji and Kiribati, where researchers found that spiritual beliefs, traditional governance mechanisms, and a short-term approach to planning were barriers to community engagement and understanding of climate change (Kuruppu, 2009; Lata and Nunn, 2012). Although widely acknowledged to be critical in small islands, few initiatives pay little more than perfunctory attention to the importance of awareness, knowledge, and understanding in climate change adaptation planning. Hence, the renewed call for adaptation initiatives to include and focus directly on these elements on an ongoing basis (e.g., Crump, 2008; Kelman and West, 2009; Kelman, 2010; Gero et al., 2011; Kuruppu and Liverman, 2011) is timely, if these barriers are to be eventually removed.

29.6.4. Mainstreaming and Integrating Climate Change into Development Plans and Policies

There is a growing body of literature that discusses the benefits and possibilities of mainstreaming or integrating climate change policies in development plans. Various mechanisms through which development agencies as well as donor and recipient countries can seek to capitalize on the opportunities to mainstream are beginning to emerge (see, e.g., Klein et al., 2007; Mertz et al., 2009). Agrawala and van Aalst (2008) provide examples, from Fiji and elsewhere, of where synergies (and trade-offs) can be found in integrating adaptation to climate change into development cooperation activities, notably in the areas of disaster risk reduction, community-based approaches to development, and building adaptive capacity. Boyd et al. (2009) support the need for more rapid integration of adaptation into development planning, to ensure that adaptation is not side-lined, or treated separately from sectoral policies. Although there are synergies and benefits to be derived from the integration of climate change and development policies, care is needed to avoid institutional overlaps, and differences in language and approach— which can give rise to conflict (Schipper and Pelling, 2006). Overall, there appears to be an emerging consensus around the views expressed by Swart and Raes (2007) that climate change and development strategies should be considered as complementary, and that some elements such as land and water management and urban, peri-urban, and rural planning provide important adaptation, development, and mitigation opportunities. Although the potential to deliver such an integrated approach may be reasonably strong in urban centers on islands, there appears to be limited capacity to mainstream climate change adaptation into local decision making in out-lying islands or peripheral areas (Nunn et al., 2013).

29.7. Adaptation and Mitigation Interactions

GHG emissions from most small islands are negligible in relation to global emissions, yet small islands will most probably be highly impacted by climate change (Srinivasan, 2010). However, many small island governments and communities have chosen to attempt to reduce their GHG emissions because of the cost and the potential co-benefits and synergies. Malta and Cyprus are obliged to do so in line with EU climate and energy policies. This section considers some of the interlinkages between adaptation and mitigation on small islands and the potential synergies, conflicts, trade-offs, and risks. Unfortunately there is relatively little research on the emissions reduction potential of small islands, and far less on the interlinkages between climate change adaptation and emissions reduction in small islands. Therefore in this section a number of assumptions are made about how and where adaptation and mitigation actions interact.

29.7.1. Assumptions/Uncertainties Associated with Adaptation and Mitigation Responses

Small islands are not homogeneous. Rather they have diverse geophysical characteristics and economic structures (see Table 29-2; Figure 29-1). Following Nunn (2009), the combination of island geography and economic types informs the extent to which adaptation and mitigation actions might interact. The geography and location of islands affect their sensitivity to hydro-meteorological and related hazards such as cyclones, floods, droughts, invasive alien species, vector-borne disease, and landslides. On the other hand, the capacity of island residents to cope is often related to income levels, resources endowment, technology, and knowledge (see Section 29.6.2).

The potential for mitigation and emissions reductions in islands depends to a large extent on their size and stage of economic development. In the small and less developed islands key "mitigation" sectors including energy, transport, industry, built environment, agriculture, forestry, or waste management sectors are generally relatively small (IPCC, 2007; Swart and Raes, 2007). Hence opportunities for emissions reductions are usually quite limited and are mostly associated with electricity generation and utilization of vehicles. More mitigation opportunities should exist in more economically advanced and larger islands that rely on forms of production that utilize fossil fuels, including manufacturing, and where vehicle usage is extensive and electricity-driven home appliances, such as air conditioners and water heaters, are extensively used.

In the absence of significant mitigation efforts at the global scale, adaptation interventions could become very costly and difficult to implement, once certain thresholds of change are reached (Birkmann, 2011; Nelson, 2011). Nicholls et al. (2011) make a similar observation with respect to coastal protection as a response to SLR. They suggest that if global mean temperatures increase by around 4°C (which may lead to sea level rise between 0.5 m and 2 m) the likelihood of successful coastal protection in some locations, such as low-lying small islands, will be low. Consequently, it is argued that the relocation of communities would be a likely outcome in such circumstances (Nicholls et al., 2011).

29.7.2. Potential Synergies and Conflicts

IPCC (2007) suggest that adaptation and mitigation interactions occur in one of four main ways: adaptations that result in GHG emissions reduction; mitigation options that facilitate adaptation; policy decisions that couple adaptation and mitigation effects; and trade-offs and synergies between adaptation and mitigation. Each of these opportunities is considered using three examples: coastal forestry, energy supply, and tourism.

Small islands have relatively large coastal zones (in comparison to land area) and most development (as well as potential mitigation and adaptation activities) are located in the coastal zone. Coastal ecosystems (coral reefs, seagrasses, and mangroves) play an important role in protecting coastal communities from wave erosion, tropical cyclones, storm surges, and even moderate tsunami waves (Cochard et al., 2008). Although coastal forests—including both endemic and exotic species, especially mangroves—are seen as effective adaptation options ("bioshields"; Feagin et al., 2010) in the coastal zones, they also play an important role in mitigation as carbon sinks (van der Werf et al., 2009). Thus, the management and conservation of mangrove forests has the potential to generate synergies between climate change adaptation and mitigation. However, despite this knowledge, population, development, and agricultural pressures have constrained the expansion of island forest carbon stocks (Fox et al., 2010) while Gilman et al. (2008) note that such pressures can also reduce the buffering capacity of coastal vegetation systems.

Renewable energy resources on small islands have only recently been considered within the context of long-term energy security (Chen et al., 2007; Praene et al., 2012). Stuart (2006) speculates that the lack of uptake of renewable technologies to date might be due to historical commitments to conventional fossil fuel-based infrastructure, and a lack of resources to undertake research and development of alternatives. Those islands that have introduced renewable energy technologies have often done so with support from international development agencies (Dornan, 2011). Despite this, there remain significant barriers to the wider institutionalization of renewable technologies in small islands. Research in Europe and the USA has shown the mitigation and cost savings benefits of Energy Service Companies (ESCOs): companies that enter into medium- to long-term performance-based contracts with energy users, invest in energy-efficiency measures in buildings and firms, and profit from the ensuing energy savings measures for the premises (see, e.g., Steinberger et al., 2009). Potential benefits exist in creating the opportunity for ESCOs to operate in small islands. Preliminary evidence from Fiji suggests that if the incentive mechanisms can be resolved, and information asymmetries between service providers and users can be aligned, ESCOs could provide an opportunity to expand renewable technologies (Dornan, 2009). IPCC (2011) presents examples of opportunities for renewable energy, including wind energy sources, as deployed in the Canary Islands.

The transition toward renewable energy sources away from fossil fuel dependence has been partly driven by economic motives, notably to avoid oil price volatility and its impact. The development of hydro-power (in Fiji, for example) necessitates protection and management of the water catchment zones, and thus could lead to improved management

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

of the water resources—a critical adaptation consideration for areas expected to experience a decrease in average rainfall as a result of climate change. While the cost effectiveness of renewable technologies is critical, placing it within the context of water adaptation could enhance project viability (Dornan, 2009). Cost-benefit analyses have shown that in southeast Mediterranean islands photovoltaic generation and storage systems may be more cost-effective than existing thermal power stations (Kaldellis, 2008; Kaldellis et al., 2009).

Energy prices in small islands are among the highest anywhere in the world, mainly because of their dependence on imported fossil fuel, and limited ability to reap the benefits of economies of scale including bulk buying. Recent studies show that the energy sectors in small islands may be transformed into sustainable growth entities mainly through the judicious exploitation of renewable energy sources, combined with the implementation of energy-efficiency measures (van Alphen et al., 2008; Banuri, 2009; Mohanty, 2012; Rogers et al., 2012). Realizing the potential for such transformation, the countries comprising the Alliance of Small Island States (AOSIS) launched SIDS Dock, which is intended to function as a "docking station" to connect the energy sector in small island developing states with the international finance, technology, and carbon markets with the objective of pooling and optimizing energy-efficiency goods and services for the benefit of the group. This initiative seeks to decrease energy dependence in small island developing states, while generating financial resources to support low carbon growth and adaptation interventions.

Many small islands rely heavily on the foreign exchange from tourism to expand and develop their economies, including the costs of mitigation and adaptation. Tourism, particularly in small islands, often relies on coastal and terrestrial ecosystems to provide visitor attractions and accommodation space. Recognizing the relationship between ecosystem services and tourism in Jamaica, Thomas-Hope and Jardine-Comrie (2007) suggest that sustainable tourism planning should include activities undertaken by the industry, that is, tertiary treatment of waste and reuse of water, as well as composting organic material and investing in renewable energy. Gössling and Schumacher (2010) and others who have examined the linkages between GHG emissions and sustainable tourism argue that the tourism sector (operators and tourists) should pay to promote sustainable tourism, especially where they benefit directly from environmental services sustained by these investments.

29.8. Facilitating Adaptation and Avoiding Maladaptation

Although there is a clear consensus that adaptation to the risks posed by global climate change is necessary and urgent in small islands, the implementation of specific strategies and options is a complex process that requires critical evaluation of multiple factors, if expected outcomes are to be achieved (Kelman and West, 2009; Barnett and O'Neill, 2012). These considerations may include, *inter alia*, prior experience with similar or related threats, efficacy of the strategies or options and their co-benefits, costs (monetary and non-monetary), availability of alternatives, and social acceptability. In addition, previous work (e.g., Adger et al., 2005) has emphasized the relevance of scale as a critical factor when assessing the efficacy and value of adaptation strategies, as the extent to which an option is perceived to be a success, failure, or maladaptive may be conditioned by whether it is being assessed as a response to climate variability (shorter term) or climate change (longer term).

As in other regions, adaptation in islands is locally delivered and context specific (Tompkins et al., 2010). Yet, sectors and communities on small islands are often so intricately linked that there are many potential pathways that may lead to maladaptation, be it via increased GHG emissions, foreclosure of future options, or burdensome opportunity costs on local communities. There is also a concern that some types of interventions may actually be maladaptive. For example, Barnett and O'Neill (2012) suggest that strategies such as resettlement and migration should be regarded as options of "last resort" on islands, as they may actually discourage viable adaptation initiatives, by fostering over-dependence on external support. They further argue that *a priori* acceptance of adaptation as an efficacious option for places like the Pacific Islands may also act as a disincentive for reducing GHG emissions (Barnett and O'Neill, 2012).

Notwithstanding the observations of Barnett and O'Neill (2012), there is a concern that early foreclosure of this option might well prove maladaptive, if location-specific circumstances show such action to be efficacious in the longer term. For example, Bunce et al. (2009) have shown that, as an adaptive response to poverty, young fishers from Rodrigues Island periodically resort to temporary migration to the main capital island, Mauritius, where greater employment prospects exist. The case study of the residents of Nauru, who contemplated resettlement

Frequently Asked Questions

FAQ 29.3 | Is it appropriate to transfer adaptation and mitigation strategies between and within small island countries and regions?

Although lessons learned from adaptation and mitigation experiences in one island or island region may offer some guidance, caution must be exercised to ensure that the transfer of such experiences is appropriate to local biophysical, social, economic, political, and cultural circumstances. If this approach is not purposefully incorporated into the implementation process, it is possible that maladaptation and inappropriate mitigation may result. It is therefore necessary to carefully assess the risk profile of each individual island so as to ensure that any investments in adaptation and mitigation are context specific. The varying risk profiles between individual small islands and small island regions have not always been adequately acknowledged in the past.

in Australia after the collapse of phosphate mining (their only revenue source) in the 1950s, provides helpful insight into the complex social, economic, and cultural challenges associated with environmentally triggered migration (Tabucanon and Opeskin, 2011). Negotiations with the Government of Australia collapsed before a mutually acceptable agreement was reached, and the Nauruans opted to abandon the proposal to relocate (Tabucanon and Opeskin, 2011). Overall, however, it is suggested that states contemplating long-term, off-island migration may wish to consider early proactive planning, as resettlement of entire communities might prove to be socially, culturally, and economically disruptive (Campbell, 2010; McMichael et al., 2012; see also Section 29.3.3.3). A related challenge facing small islands is the need to find the middle ground between resettlement and objective assessment of other appropriate adaptation choices.

Similarly, although insurance is being promoted as an element of the overall climate change response strategy in some island regions, for example, the Caribbean, concerns have been expressed about possible linkages to maladaptation. The potential consequences include the imposition of exorbitant premiums that are beyond the capacity of resource-scarce governments as the perception of climate change risks increase, discriminatory coverage of sectors that may not align with local priorities, and tacit encouragement for the state, individuals, and the private sector to engage in behavior that is not risk-averse, for example, development in hazard-prone areas (Herweijer et al., 2009; Linnerooth-Bayer et al., 2011; Thomas and Leichenko, 2011; van Nostrand and Nevius, 2011). Likewise, although the exploitation of renewable energy is vital to the sustainable development of small islands, more attention needs to be paid to the development of energy storage technologies, if rapid transition from conventional fuels is to be achieved in an efficient manner. This is especially important in the case of intermittent energy sources (e.g., solar and wind), as the cost of current storage technologies can frustrate achievement of full conversion to renewable energy. Thus to avoid the possibility of maladaptation in the sector, countries may wish to consider engaging in comprehensive planning, including considerations relating to energy storage (Krajačić et al., 2010; Bazilian et al., 2011).

Recent studies have demonstrated that opportunities exist in island environments for avoiding maladaptation. Studies have shown that decisions about adaptation choices and their implementation are best facilitated where there is constructive engagement with the communities at risk, in a manner that fosters transparency and trust (van Aalst et al., 2008; López-Marrero, 2010). Further, some analysts argue that adaptation choices are often subjective in nature and suggest that participatory stakeholder involvement can yield valuable information about the priorities and expectations that communities attach to the sector for which adaptation is being sought.

The point is underscored by Moreno and Becken (2009), whose study of the tourism sector on the Mamanuca islands (Fiji) clearly demonstrates that approaches that explicitly integrate stakeholders into each step of the process from vulnerability assessment right through to consideration of alternatives measures can provide a sound basis for assisting destinations with the implementation of appropriate adaptation interventions. This view is supported by Dulal et al. (2009), who argue that the most vulnerable groups in the Caribbean—the poor, elderly, indigenous communities, and rural children—will be at greater risk of being marginalized, if adaptation is not informed by equitable and participatory frameworks.

Other studies reveal that new paradigms whose adoption can reduce the risk of maladaptation in island environments are emerging across various sectors. In the area of natural resource management, Hansen et al. (2010) suggest that the use of protected areas for climate refugia, reduction of non-climate stressors on ecosystems, and adoption of adaptive management approaches, combined with reduction of GHG emissions wherever possible, may prove to be more effective response strategies than traditional conservation approaches. Other strategic approaches, including the implementation of multi-sectoral and cross-sectoral measures, also facilitate adaptation in a more equitable, integrated, and sustainable manner. Similarly, "no-regret" measures such as wastewater recycling, trickle irrigation, conversion to non-fossil fuel-based energy, and transportation which offer collateral benefits with or without the threat of climate change and "low-regret" strategies, which may increase existing operational costs only marginally, are becoming increasingly attractive options to island governments (Gravelle and Mimura, 2008; Heltberg et al., 2009; Howard et al., 2010). Together, these constitute valid risk management approaches, as they are designed to assist communities in making prudent, but necessary decisions in the face of an uncertain future.

Some authors suggest that caution is needed to ensure that donors are not driving the adaptation and mitigation agenda in small islands, as there is a risk that donor-driven adaptation or mitigation may not always address the salient challenges on small islands, and may lead to inadequate adaptation or a waste of scarce resources (Nunn, 2009; Barnett, 2010). Others argue that donor-led initiatives may unintentionally cause enhanced vulnerability by supporting adaptation strategies that are externally derived, rather than optimizing the benefits of local practices that have proven to be efficacious through time (Reenberg et al., 2008; Campbell and Beckford, 2009; Kelman and West, 2009).

29.9. Research and Data Gaps

Several advances have taken place in our understanding of the observed and potential effects of climate change on small islands since the AR4. These cover a range of themes including dynamic downscaling of scenarios appropriate for small islands; impacts of transboundary processes generated well beyond the borders of an individual nation or island; barriers to adaptation in small islands and how they may be overcome; the relationships between climate change adaptation and disaster risk reduction; and the relationships between climate change adaptation, maladaptation, and sustainable development.

It is also evident that much further work is required on these themes in small island situations, especially comparative research. Important information and data gaps and many uncertainties still exist on impacts, vulnerability, and adaptation in small islands. These include:

- **Lack of climate change and socioeconomic scenarios and data at the required scale for small islands**. Although some advances have been made (Taylor et al., 2007; Australian Bureau of Meteorology and CSIRO, 2011a,b), much of the work in the

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Caribbean, Pacific and Indian Oceans, and Mediterranean islands is focused at the regional scale rather than being country specific. Because most socioeconomic decisions are taken at the local level, there is a need for a more extensive database of simulations of future small island climates and socioeconomic conditions at smaller spatial scales.

- **Difficulties in detecting and attributing past impacts on small islands to climate change processes**. Further investigation of the observed impacts of weather, climate, and ocean events that may be related to climate change is required to clarify the relative role of climate change and non-climate change drivers.
- **Uncertainty in the projections is not a sufficiently valid reason to postpone adaptation planning in small islands**. In several small islands adaptation is being progressed without a full understanding of past or potential impacts and vulnerability. Although assessment of future impacts is hampered because of uncertainty in climate projections at the local island level, alternative scenarios based on a general understanding of broad trends could be used in vulnerability and sensitivity studies to guide adaptation strategies.
- **Need for a range of climate change-related projections beyond temperature and sea level**. Generally, climate-model projections of temperature and sea level have been satisfactory, but there are strong requirements for projections for other variables that are of critical importance to small islands. These include rainfall and drought, wind direction and strength, tropical storms and wave climate, and recognition that transboundary processes are also significant in a small island context. Although some such work has been undertaken for some parts of the Pacific (Australian Bureau of Meteorology and CSIRO, 2011a,b), similar work still needs to be carried out in other small island regions. In addition, the reliability of existing projections for some of the other parameters needs to be improved and the data should be in suitable formats for use in risk assessments.
- **Need to acknowledge the heterogeneity and complexity of small island states and territories.** Although small islands have several characteristics in common, neither the variety nor complexity of small islands is sufficiently reflected in the literature. Thus, transfer of data and practices from a continental situation, or from one small island state to another, needs to be done with care and in a manner that takes full cognizance of such heterogeneity and complexity.
- **Within-country and -territory differences need to be better understood.** Many of the environmental and human impacts reported in the literature on islands have been attributed to the whole country, when in fact they refer only to the major center or town or region. There is need for more work on rural areas, outer islands, and secondary communities. Several examples of such research have been cited in this chapter. Also it should be noted that some small island states are single islands and others highly fragmented multiple islands.
- **Lack of investment and attention to climate and environmental monitoring frameworks in small islands.** A fundamental gap in the ability to improve empirical understanding of present and future climate change impacts is the lack of climate and environmental monitoring frameworks that in turn hampers the level of confidence with which adaptation responses can be designed and implemented.
- **Economic and social costs of climate change impacts and adaptation options are rarely known.** In small island states and territories the costs of past weather, climate, and ocean events are poorly known and further research is required to identify such costs, and to determine the economic and societal costs of climate change impacts and the costs of adaptation options to minimize those impacts.

The foregoing list is a sample of the gaps, needs, and research agenda that urgently need to be filled for small islands. Although some countries have begun to fill these gaps, this work needs to be replicated and expanded across all island regions to improve the database available for ongoing climate change assessments. Such information would raise the level of confidence in the adaptation planning and implementation process in small islands.

References

ADB, 2009: *Natural Catastrophe Risk Insurance Mechanisms for Asia and the Pacific.* Asian Development Bank (ADB), Manila, Philippines, 67 pp.

Adger, W.N. and K. Brown, 2009: Vulnerability and resilience to environmental change: ecological and social perspectives. In: *A Companion to Environmental Geography* [Castree, N., D. Demeritt, D. Liverman, and B. Rhoads (eds.)]. Blackwell Publishing Ltd., Chichester, UK, pp. 109-122.

Adger, W., N. Arnell, and E. Tompkins, 2005: Successful adaptation to climate change across scales. *Global Environmental Change*, **5(2)**, 77-86.

Adger, W., S. Dessai, M. Goulden, M. Hulme, I. Lorenzoni, D. Nelson, L. Naess, J. Wolf, and A. Wreford, 2009: Are there social limits to adaptation to climate change? *Climatic Change*, **93(3)**, 335-354.

Afifi, T., K. Warner, and T. Rosenfeld, 2013: Environmentally induced migration, theoretical and methodological research challenges. In: *The Encyclopedia of Global Human Migration* [Ness, I. (ed.)]. Wiley-Blackwell Publishing Ltd., Chichester, UK, doi:10.1002/9781444351071.wbeghm197.

Agrawala, S. and M. van Aalst, 2008: Adapting development cooperation to adapt to climate change. *Climate Policy*, **8(2)**, 183-193.

Akerlof, K., R. DeBono, P. Berry, A. Leiserowitz, C. Roser-Renouf, K.-L. Clarke, A. Rogaeva, M.C. Nisbet, M.R. Weathers, and E.W. Maibach, 2010: Public perceptions of climate change as a human health risk: surveys of the United States, Canada and Malta. *International Journal of Environmental Research and Public Health*, **7(6)**, 2559-2606.

Albins, M.A. and M.A. Hixon, 2008: Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. *Marine Ecology Progress Series*, **367**, 233-238.

Albins, M.A. and M.A. Hixon, 2013: Worst case scenario: potential long-term effects of invasive predatory lionfish (*Pterois volitans*) on Atlantic and Caribbean coral-reef communities. *Environmental Biology of Fishes*, **96(10-11)**, 1151-1157.

Aligizaki, K. and G. Nikolaidis, 2008: Morphological identification of two tropical dinoflagellates of the genera *Gambierdiscus* and *Sinophysis* in the Mediterranean Sea. *Journal of Biological Research-Thessaloniki*, **9**, 75-82.

Al-Jeneid, S., M. Bahnassy, S. Nasr, and M. El Raey, 2008: Vulnerability assessment and adaptation to the impacts of sea level rise on the Kingdom of Bahrain. *Mitigation and Adaptation Strategies for Global Change*, **13(1)**, 87-104.

Alling, A., O. Doherty, H. Logan, L. Feldman, and P. Dustan, 2007: Catastrophic coral mortality in the remote Central Pacific Ocean: Kiribati, Phoenix Islands. *Atoll Research Bulletin*, **551**, 1-19.

Anagnostou, C., P. Antoniou, and G. Hatiris, 2011: Erosion of a depositional coast in NE Rhodos Island (SE Greece) and assessment of the best available measures for coast protection. (Proceedings, 11th International Coastal Symposium, May 9-14, 2011, Szczecin, Poland.) *Journal of Coastal Research*, **(64 SI)**, 1316-1319.

Anderson, M.G., E. Holcombe, J.R. Blake, F. Ghesquire, N. Holm-Nielsen, and T. Fisseha, 2011: Reducing landslide risk in communities: evidence from the Eastern Caribbean. *Applied Geography*, **31(2)**, 590-599.

Angelo, C.L. and C.C. Daehler, 2013: Upward expansion of fire-adapted grasses along a warming tropical elevation gradient. *Ecography*, **36(5)**, 551-559.

Angelucci, F. and P. Conforti, 2010: Risk management and finance along value chains of Small Island Developing States. Evidence from the Caribbean and the Pacific. *Food Policy*, **35(6)**, 565-575.

Anthoff, D., R.J. Nicholls, and R.S.J. Tol, 2010: The economic impact of substantial sea-level rise. *Mitigation and Adaptation Strategies for Global Change*, **15(4)**, 321-335.

Atkinson, C.T. and D.A. LaPointe, 2009: Introduced avian diseases, climate change, and the future of Hawaiian honeycreepers. *Journal of Avian Medicine and Surgery*, **23(1)**, 53-63.

Audefroy, J.F., 2011: Haiti: post-earthquake lessons learned from traditional construction. *Environment and Urbanization*, **23(2)**, 447-462.

Australian Bureau of Meteorology and CSIRO, 2011a: *Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview*. The Pacific Climate Change Science Program (PCCSP), a key activity under the Australian government's International Climate Change Adaptation Initiative (ICCAI), funded by AusAID, managed by the Australian Department of the Environment (DOE) and delivered by a partnership between the Australian Bureau of Meteorology (BOM) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), PCCSP, Aspendale, VIC, Australia, 257 pp.

Australian Bureau of Meteorology and CSIRO, 2011b: *Climate Change in the Pacific: Scientific Assessment and New Research. Volume 2: Country Reports Overview*. The Pacific Climate Change Science Program (PCCSP), a key activity under the Australian government's International Climate Change Adaptation Initiative (ICCAI), funded by AusAID, managed by the Australian Department of the Environment (DOE) and delivered by a partnership between the Australian Bureau of Meteorology (BOM) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), PCCSP, Aspendale, VIC, Australia, 273 pp.

Baider, C. and F.B.V. Florens, 2011: Control of invasive alien weeds averts imminent plant extinction. *Biological Invasions*, **13(12)**, 2641-2646.

Baker, J.L., 2012: *Climate Change, Disaster Risk, and the Urban Poor: Cities Building Resilience for a Changing World.* Urban Development Series, The International Bank for Reconstruction and Development / The World Bank, World Bank Publications, Washington, DC, USA, 297 pp.

Ballu, V., M.-N. Bouin, P. Siméoni, W.C. Crawford, S. Calmant, J.-M. Boré, T. Kanas, and B. Pelletier, 2011: Comparing the role of absolute sea-level rise and vertical tectonic motions in coastal flooding, Torres Islands (Vanuatu). *Proceedings of the National Academy of Sciences of the United States of America*, **108(32)**, 13019-13022.

Banuri, T., 2009: Climate change and sustainable development. *Natural Resources Forum*, **33(4)**, 257-258.

Barnett, J., 2001: Adapting to climate change in Pacific Island Countries: the problem of uncertainty. *World Development*, **29(6)**, 977-993.

Barnett, J., 2010: Climate change science and policy, as if people mattered. In: *Climate Change, Ethics and Human Security* [O'Brien, K., A.L. St. Clair, and B. Kristoffersen (eds.)]. Cambridge University Press, Cambridge, UK, pp. 47-62.

Barnett, J., 2011: Dangerous climate change in the Pacific Islands: food production and food security. *Regional Environmental Change*, **11(1)**, 229-237.

Barnett, J. and J. Campbell, 2010: *Climate Change and Small Island States: Power, Knowledge and the South Pacific.* Earthscan Ltd., London, UK and Washington, DC, USA, 218 pp.

Barnett, J. and N. Chamberlain, 2010: Migration as climate change adaptation: implications for the Pacific. In: *Climate Change and Migration, South Pacific Perspectives* [Burson, B. (ed.)]. Institute of Policy Studies, Victoria University of Wellington, Wellington, New Zealand, pp. 51-60.

Barnett, J. and S.J. O'Neill, 2012: Islands, resettlement and adaptation. *Nature Climate Change*, **2**, 8-10.

Barnett, J. and M. Webber, 2010: *Accommodating Migration to Promote Adaptation to Climate Change.* Policy Research Working Paper No. 5270, Background Paper prepared for the Secretariat of the Swedish Commission on Climate Change and Development and the World Bank World Development Report 2010: Development and Climate Change, The International Bank for Reconstruction and Development / The World Bank, Development Economics Vice Presidency, Washington, DC, USA, 62 pp.

Barnett, J., S. Lambert, and I. Fry, 2008: The hazards of indicators: insights from the environmental vulnerability index. *Annals of the Association of American Geographers*, **98(1)**, 102-119.

Bassiouni, M. and D.S. Oki, 2013: Trends and shifts in streamflow in Hawai'i, 1913-2008. *Hydrological Processes*, **27(10)**, 1484-1500.

Bazilian, M., H. Rogner, M. Howells, S. Hermann, D. Arent, D. Gielen, P. Steduto, A. Mueller, P. Komor, R.S.J. Tol, and K.K. Yumkella, 2011: Considering the energy, water and food nexus: towards an integrated modelling approach. *Energy Policy*, **39(12)**, 7896-7906.

Becker, M., B. Meyssignac, C. Letetrel, W. Llovel, A. Cazenave, and T. Delcroix, 2012: Sea level variations at tropical Pacific islands since 1950. *Global and Planetary Change*, **80-81**, 85-98.

Bedford, R. and C. Bedford, 2010: International migration and climate change: a post-Copenhagen perspective on options for Kiribati and Tuvalu. In: *Climate Change and Migration: South Pacific Perspectives* [Burson, B. (ed.)]. Institute of Policy Studies, Victoria University of Wellington, Wellington, New Zealand, pp. 89-134.

Béguin, A., S. Hales, J. Rocklöv, C. Åström, V.R. Louis, and R. Sauerborn, 2011: The opposing effects of climate change and socio-economic development on the global distribution of malaria. *Global Environmental Change*, **21(4)**, 1209-1214.

Bell, J.D., J.E. Johnson, and A.J. Hobday (eds.), 2011: *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change.* Secretariat of the Pacific Community, Noumea, New Caledonia, 925 pp.

Bell, J.D., C. Reid, M.J. Batty, P. Lehodey, L. Rodwell, A.J. Hobday, J.E. Johnson, and A. Demmke, 2013: Effects of climate change on oceanic fisheries in the tropical Pacific: implications for economic development and food security. *Climatic Change*, **119(1)**, 199-212.

Benning, T.L., D. LaPointe, C.T. Atkinson, and P.M. Vitousek, 2002: Interactions of climate change with biological invasions and land use in the Hawaiian Islands: modeling the fate of endemic birds using a geographic information system. *Proceedings of the National Academy of Sciences of the United States of America*, **99(22)**, 14246-14249.

Berringer, A.C.S., 2012: Climate change and emigration: comparing "sinking islands" and Jamaica. *Miradas en Movimiento*, **SI:** Naturally Immigrants, January 2012, 106-120.

Biermann, F. and I. Boas, 2010: Preparing for a warmer world: towards a global governance system to protect climate refugees. *Global Environmental Politics*, **10(1)**, 60-88.

Bijlsma, L., C.N. Ehler, R.J.T. Klein, S.M. Kulshrestha, R.F. McLean, N. Mimura, R.J. Nicholls, L.A. Nurse, H. Perez Nieto, E.Z. Stakhiv, R.K. Turner, and R.A. Warrick, 1996: Coastal zones and small islands. In: *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 289-324.

Birkmann, J., 2011: First- and second-order adaptation to natural hazards and extreme events in the context of climate change. *Natural Hazards*, **58(2)**, 811-840.

Bishop, M.L., 2012: The political economy of small states: enduring vulnerability? *Review of International Political Economy*, **19(5)**, 942-960.

Black, R., W.N. Adger, N.W. Arnell, S. Dercon, A. Geddes, and D. Thomas, 2011: The effect of environmental change on human migration. *Global Environmental Change*, **21(1 Suppl.)**, S3-S11.

Blackburn, T.M., P. Cassey, R.P. Duncan, K.L. Evans, and K.J. Gaston, 2004: Avian extinction and mammalian introductions on oceanic islands. *Science*, **305(5692)**, 1955-1958.

Blancard, S. and J. Hoarau, 2013: A new sustainable human development indicator for small island developing states: a reappraisal from data envelopment analysis. *Economic Modelling*, **30**, 623-635.

Bokhorst, S., A. Huiskes, P. Convey, and R. Aerts, 2007: The effect of environmental change on vascular plant and cryptogam communities from the Falkland Islands and the Maritime Antarctic. *BMC Ecology*, **7(1)**, 15, doi:10.1186/1472-6785-7-15.

Bokhorst, S., A. Huiskes, P. Convey, P.M. van Bodegom, and R. Aerts, 2008: Climate change effects on soil arthropod communities from the Falkland Islands and the Maritime Antarctic. *Soil Biology and Biochemistry*, **40(7)**, 1547-1556.

Boyd, E., N. Grist, S. Juhola, and V. Nelson, 2009: Exploring development futures in a changing climate: frontiers for development policy and practice. *Development Policy Review*, **27(6)**, 659-674.

Brandt, M.E. and J.W. McManus, 2009: Disease incidence is related to bleaching extent in reef-building corals. *Ecology*, **90(10)**, 2859-2867.

Breckwoldt, A. and H. Seidel, 2012: The need to know what to manage – community-based marine resource monitoring in Fiji. *Current Opinion in Environmental Sustainability*, **4(3)**, 331-337.

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Bridges, K.W. and W.C. McClatchey, 2009: Living on the margin: ethnoecological insights from Marshall Islanders at Rongelap atoll. *Global Environmental Change*, **19(2)**, 140-146.

Briguglio, L., G. Cordina, N. Farrugia, and S. Vella, 2009: Economic vulnerability and resilience: concepts, measurements. *Oxford Development Studies*, **37(3)**, 229-247.

Brown, J.N., J.R. Brown, C. Langlais, R. Colman, J. Risbey, B.F. Murphy, A. Moise, A.S. Gupta, I. Smith, and L. Wilson, 2013a: Exploring qualitative regional climate projections: a case study for Nauru. *Climate Research*, **58(2)**, 165-182.

Brown, J.N., A.S. Gupta, J.R. Brown, L.C. Muir, J.S. Risbey, P. Whetton, X. Zhang, A. Ganachaud, B. Murphy, and S.E. Wijffels, 2013b: Implications of CMIP3 model biases and uncertainties for climate projections in the western tropical Pacific. *Climatic Change*, **119(1)**, 147-161.

Bunce, M., L. Mee, L.D. Rodwell, and R. Gibb, 2009: Collapse and recovery in a remote small island – a tale of adaptive cycles or downward spirals? *Global Environmental Change*, **19(2)**, 213-226.

Bush, D.M., W.J. Neal, and C.W. Jackson, 2009: Summary of Puerto Rico's vulnerability to coastal hazards: risk, mitigation, and management with examples. *Geological Society of America Special Papers*, **460**, 149-165.

Buzinde, C.N., D. Manuel-Navarrete, E.E. Yoo, and D. Morais, 2010: Tourists' perceptions in a climate of change: eroding destinations. *Annals of Tourism Research*, **37(2)**, 333-354.

Byravan, S. and S.C. Rajan, 2006: Providing new homes for climate change exiles. *Climate Policy*, **6(2)**, 247-252.

Cahoon, D.R., P. Hensel, J. Rybczyk, K.L. McKee, C.E. Proffitt, and B.C. Perez, 2003: Mass tree mortality leads to mangrove peat collapse at Bay Islands, Honduras after Hurricane Mitch. *Journal of Ecology*, **91(6)**, 1093-1105.

Calado, H., P. Borges, M. Phillips, K. Ng, and F. Alves, 2011: The Azores archipelago, Portugal: improved understanding of small island coastal hazards and mitigation measures. *Natural Hazards*, **58(1)**, 427-444.

Cambers, G., 2009: Caribbean beach changes and climate change adaptation. *Aquatic Ecosystem Health and Management*, **12(2)**, 168-176.

Campbell, D. and C. Beckford, 2009: Negotiating uncertainty: Jamaican small farmers' adaptation and coping strategies, before and after hurricanes – a case study of Hurricane Dean. *Sustainability*, **1(4)**, 1366-1387.

Campbell, J.D., M.A. Taylor, T.S. Stephenson, R.A. Watson, and F.S. Whyte, 2011: Future climate of the Caribbean from a regional climate model. *International Journal of Climatology*, **31(12)**, 1866-1878.

Campbell, J., 2009: Islandness: vulnerability and resilience in Oceania. *Shima: The International Journal of Research into Island Cultures*, **3(1)**, 85-97.

Campbell, J., 2010: Climate change and population movement in Pacific Island Countries. In: *Climate Change and Migration: South Pacific Perspectives* [Burson, B. (ed.)]. Institute of Policy Studies, Victoria University of Wellington, Wellington, New Zealand, pp. 29-50.

Campbell, J.R., M. Goldsmith, and K. Koshy, 2005: *Community Relocation as an Option for Adaptation to the Effects of Climate Change and Climate Variability in Pacific Island Countries (PICs).* Asia-Pacific Network for Global Change Research, Kobe, Japan, 61 pp.

Campbell, S.J., L.J. McKenzie, and S.P. Kerville, 2006: Photosynthetic responses of seven tropical seagrasses to elevated seawater temperature. *Journal of Experimental Marine Biology and Ecology*, **330(2)**, 455-468.

Cantin, N.E., A.N. Cohen, K.B. Karnauskas, A.N. Tarrant, and D.C. McCorkle, 2010: Ocean warming slows coral growth in the central Red Sea. *Science*, **329(5989)**, 322-325.

Cardona, O.D., 2007: *Indicators of Disaster Risk and Risk Management: Program for Latin American and the Caribbean – Summary Report.* Sustainable Development Department, Environment Division, Inter-American Development Bank, Washington, DC, USA, 44 pp.

Carilli, J.E., R.D. Norris, B. Black, S.M. Walsh, and M. McField, 2010: Century-scale records of coral growth rates indicate that local stressors reduce coral thermal tolerance threshold. *Global Change Biology*, **16(4)**, 1247-1257.

Carpenter, R.C. and P.J. Edmunds, 2006: Local and regional scale recovery of *Diadema* promotes recruitment of scleractinian corals. *Ecology Letters*, **9(3)**, 268-277.

Cashman, A., L. Nurse, and J. Charlery, 2010: Climate change in the Caribbean: the water management implications. *Journal of Environment and Development*, **19(1)**, 42-67.

Caujape-Castells, J., A. Tye, D.J. Crawford, A. Santos-Guerra, A. Sakai, K. Beaver, W. Lobin, F. Vincent Florens, M. Moura, and R. Jardim, 2010: Conservation of oceanic island floras: present and future global challenges. *Perspectives in Plant Ecology, Evolution and Systematics*, **12(2)**, 107-129.

Cazenave, A. and W. Llovel, 2010: Contemporary sea level rise. *Annual Review of Marine Science*, **2**, 145-173.

Cazenave, A. and F. Remy, 2011: Sea level and climate: measurements and causes of changes. *Wiley Interdisciplinary Reviews: Climate Change*, **2(5)**, 647-662.

CCRIF, 2008: *The Caribbean Catastrophe Risk Insurance Facility Annual Report 2007-2008.* The Caribbean Catastrophe Risk Insurance Facility (CCRIF), George Town, Grand Cayman, Cayman Islands, 34 pp.

Cervino, J.M., F.L. Thompson, B. Gomez-Gil, E.A. Lorence, T.J. Goreau, R.L. Hayes, K.B. Winiarski-Cervino, G.W. Smith, K. Hughen, and E. Bartels, 2008: The *Vibrio* core group induces yellow band disease in Caribbean and Indo-Pacific reef-building corals. *Journal of Applied Microbiology*, **105(5)**, 1658-1671.

Chadee, D.D., 2009: Dengue cases and *Aedes aegypti* indices in Trinidad, West Indies. *Acta Tropica*, **112(2)**, 174-180.

Chadee, D., B. Shivnauth, S. Rawlins, and A. Chen, 2007: Climate, mosquito indices and the epidemiology of dengue fever in Trinidad (2002-2004). *Annals of Tropical Medicine and Parasitology*, **101(1)**, 69-77.

Chan, W.H., Y.L. Mak, J.J. Wu, L. Jin, W.H. Sit, J.C.W. Lam, Y. Sadovy de Mitcheson, L.L. Chan, P.K.S. Lam, and M.B. Murphy, 2011: Spatial distribution of ciguateric fish in the Republic of Kiribati. *Chemosphere*, **84(1)**, 117-123.

Charlery, J. and L. Nurse, 2010: Areal downscaling of global climate models: an approach that avoids data remodelling. *Climate Research*, **43(3)**, 241-249.

Chaves, L.F. and J.M. Koenraadt, 2010: Climate change and highland malaria: fresh air in a hot debate. *The Quarterly Review of Biology*, **85(1)**, 27-55.

Chen, F., N. Duic, L.M. Alves, and M.d.G. Carvalho, 2007: Renewislands – Renewable energy solutions for islands. *Renewable and Sustainable Energy Reviews*, **8(11)**, 1888-1902.

Chen, I., H.J. Shiu, S. Benedick, J.D. Holloway, V.K. Chey, H.S. Barlow, J.K. Hill, and C.D. Thomas, 2009: Elevation increases in moth assemblages over 42 years on a tropical mountain. *Proceedings of the National Academy of Sciences of the United States of America*, **106(5)**, 1479-1483.

Christenhusz, M.J.M. and T.K. Toivonen, 2008: Giants invading the tropics: the oriental vessel fern, *Angiopteris evecta*. *Biological Invasions*, **10(8)**, 1215-1228.

Church, J.A. and N.J. White, 2011: Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics*, **32(4-5)**, 585-602.

Cinner, J.E., T.R. McClanahan, N.A.J. Graham, T.M. Daw, J. Maina, S.M. Stead, A. Wamukota, K. Brown, and Ö. Bodin, 2012: Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change*, **22(1)**, 12-20.

Cochard, R., S.L. Ranamukhaarachchi, G.P. Shivakoti, O.V. Shipin, P.J. Edwards, and K.T. Seeland, 2008: The 2004 tsunami in Aceh and Southern Thailand: a review on coastal ecosystems, wave hazards and vulnerability. *Perspectives in Plant Ecology Evolution and Systematics*, **10(1)**, 3-40.

Connell, J., 2012: Population resettlement in the Pacific: lessons from a hazardous history? *Australian Geographer*, **43(2)**, 127-142.

Connell, J. and J.P. Lea, 2002: *Urbanisation in the Island Pacific: Towards Sustainable Development.* Routledge, London, UK and New York, NY, USA, 240 pp.

Cooper, A., D. Jackson, and S. Gore, 2013: A groundswell event on the coast of the British Virgin Islands: variability in morphological impact. (Proceedings, 12th International Coastal Symposium, Plymouth, England.) *Journal of Coastal Research*, **(65 SI)**, 696-701.

Coutinho, R., J. Pacheco, N. Wallenstein, A. Pimentel, R. Marques, and R. Silva, 2009: Integrating geological knowledge in planning methods for small islands coastal plans. (Proceedings, 10th International Coastal Symposium, Lisbon, Portugal.) *Journal of Coastal Research*, **(56 SI)**, 1199-1203.

Cronk, Q., 1997: Islands: stability, diversity, conservation. *Biodiversity & Conservation*, **6(3)**, 477-493.

Crump, J., 2008: Snow, sand, ice and sun: climate change and equity in the Arctic and Small Island Developing States. *Sustainable Development Law and Policy*, **8(3)**, 8-13.

Cruz, M., R. Aguiar, A. Correia, T. Tavares, J. Pereira, and F. Santos, 2009: Impacts of climate change on the terrestrial ecosystems of Madeira. *International Journal of Design and Nature and Ecodynamics*, **4(4)**, 413-422.

Cummins, J.D. and O. Mahul, 2009: *Catastrophe Risk Financing in Developing Countries: Principles for Public Intervention.* The International Bank for Reconstruction and Development / The World Bank, World Bank Publications, Washington, DC, USA, 268 pp.

Danovaro, R., S.F. Umani, and A. Pusceddu, 2009: Climate Change and the potential spreading of marine mucilage and microbial pathogens in the Mediterranean Sea. *PLoS ONE*, **4(9)**, e7006, doi:10.1371/journal.pone.0007006.

Dawson, J.L. and S.G. Smithers, 2010: Shoreline and beach volume change between 1967 and 2007 at Raine Island, Great Barrier Reef, Australia. *Global and Planetary Change*, **72(3)**, 141-154.

de Haas, H., 2011: Mediterranean migration futures: patterns, drivers and scenarios. *Global Environmental Change*, **21(1 Suppl.)**, S59-S69.

de Scally, F.A., 2008: Historical tropical cyclone activity and impacts in the Cook Islands. *Pacific Science*, **62(4)**, 443-459.

De'ath, G., J.M. Lough, and K.C. Fabricius, 2009: Declining coral calcification on the Great Barrier Reef. *Science*, **323(5910)**, 116-119.

Dema, B., 2012: Sea level rise and the freely associated states: addressing environmental migration under the compacts of free association. *Columbia Journal of Environmental Law*, **37(1)**, 177-204.

Didham, R.K., J.M. Tylianakis, M.A. Hutchison, R.M. Ewers, and N.J. Gemmell, 2005: Are invasive species the drivers of ecological change? *Trends in Ecology and Evolution*, **20(9)**, 470-474.

Donelson, J.M., P.L. Munday, M.I. McCormick, N.W. Pankhurst, and P.M. Pankhurst, 2010: Effects of elevated water temperature and food availability on the reproductive performance of a coral reef fish. *Marine Ecology Progress Series*, **401**, 233-243.

Donn, W.L. and W.T. McGuinness, 1959: Barbados storm swell. *Journal of Geophysical Research*, **64(12)**, 2341-2349.

Donner, S.D., 2009: Coping with commitment: projected thermal stress on coral reefs under different future scenarios. *PLoS ONE*, **4(6)**, e5712, doi:10.1371/journal.pone.0005712.

Donner, S.D., T. Kirata, and C. Vieux, 2010: Recovery from the 2004 coral bleaching event in the Gilbert Islands, Kiribati. *Atoll Research Bulletin*, **587**, 1-25.

Dornan, M., 2009: Methods for assessing the contribution of renewable technologies to energy security: the electricity sector of Fiji. *Pacific Economic Bulletin*, **24(3)**, 71-91.

Dornan, M., 2011: Solar-based rural electrification policy design: the Renewable Energy Service Company (RESCO) model in Fiji. *Renewable Energy*, **36(2)**, 797-803.

Dorville, J.-F. and N. Zahibo, 2010: Hurricane Omar waves impact on the west coast of the Guadeloupe Island, October 2008. *The Open Oceanography Journal*, **4**, 83-91.

Dulal, H.B., K.U. Shah, and N. Ahmad, 2009: Social equity considerations in the implementation of Caribbean climate change adaptation policies. *Sustainability*, **1(3)**, 363-383.

Dumaru, P., 2010: Community-based adaptation: enhancing community adaptive capacity in Druadrua Island, Fiji. *Wiley Interdisciplinary Reviews: Climate Change*, **1(5)**, 751-763.

Dunne, R.P., S.M. Barbosa, and P.L. Woodworth, 2012: Contemporary sea level in the Chagos Archipelago, central Indian Ocean. *Global and Planetary Change*, **82-83**, 25-37.

Dupon, J.-F., 1987: Les atolls et le risque cyclonique: le cas des Tuamotu [The atolls and the potential cyclone: the case of the Tuamotu Islands]. *Cahiers des Sciences Humaines*, **23(3-4)**, 567-599 (in French).

Duvat, V., 2009: Beach erosion management in small island developing states: Indian Ocean case studies. In: *Coastal Processes* [Brebbia, C.A., G. Benassai, and G.R. Rodriguez (eds.)]. Proceedings of the International Conference on Physical Coastal Processes, Management and Engineering, September 14-16, Malta, WIT Press, Southampton, UK, pp. 149-160.

Duvat, V., 2013: Coastal protection structures in Tarawa Atoll, Republic of Kiribati. *Sustainability Science*, **8(3)**, 363-379.

Eakin, C.M., J.M. Lough, and S.F. Heron, 2009: Climate variability and change: monitoring data and evidence for increased coral bleaching stress. In: *Coral Bleaching: Patterns, Processes, Causes and Consequences* [van Oppen, M.J.H. and J.M. Lough (eds.)]. Ecological Studies, Vol. 205, Springer-Verlag, Berlin, Germany, pp. 41-67.

Ellison, J.C., 1993: Mangrove retreat with rising sea-level, Bermuda. *Estuarine, Coastal and Shelf Science*, **37(1)**, 75-87.

Ellison, J.C., 2009: Wetlands of the Pacific Island region. *Wetlands Ecology and Management*, **17(3)**, 169-206.

Emmanuel, K. and B. Spence, 2009: Climate change implications for water resource management in Caribbean tourism. *Worldwide Hospitality and Tourism Themes*, **1(3)**, 252-268.

Englund, R.A., 2008: Invasive species threats to native aquatic insect biodiversity and conservation measures in Hawai'i and French Polynesia. *Journal of Insect Conservation*, **12(3-4)**, 415-428.

ESCAP and UNISDR, 2010: The Asia-Pacific disaster report, 2010. In: *Protecting Development Gains: Reducing Disaster Vulnerability and Building Resilience in Asia and the Pacific*. ESCAP and UNISDR, Bangkok, Thailand, 129 pp.

Etienne, S., 2012: Marine inundation hazards in French Polynesia: geomorphic impacts of Tropical Cyclone Oli in February 2010. In: *Natural Hazards in the Asia – Pacific Region: Recent Advances and Emerging Concepts* [Terry, J.P. and J. Goff (eds.)]. Geological Society Special Publication No. 361, The Geological Society Publishing House, Bath, UK, pp. 21-39.

Etienne, S. and J.P. Terry, 2012: Coral boulders, gravel tongues and sand sheets: features of coastal accretion and sediment nourishment by Cyclone Tomas (March 2010) on Taveuni Island, Fiji. *Geomorphology*, **175-176**, 54-65.

Fazey, I., N. Pettorelli, J. Kenter, D. Wagatora, and D. Schuett, 2011: Maladaptive trajectories of change in Makira, Solomon Islands. *Global Environmental Change*, **21(4)**, 1275-1289.

Feagin, R.A., N. Mukherjee, K. Shanker, A.H. Baird, J. Cinner, A.M. Kerr, N. Koedam, A. Sridhar, R. Arthur, L.P. Jayatissa, D. Lo Seen, M. Menon, S. Rodriguez, M. Shamsuddoha, and F. Dahdouh-Guebas, 2010: Shelter from the storm? Use and misuse of coastal vegetation bioshields for managing natural disasters. *Conservation Letters*, **3(1)**, 1-11.

Ferdinand, I., G. O'Brien, P. O'Keefe, and J. Jayawickrama, 2012: The double bind of poverty and community disaster risk reduction: a case study from the Caribbean. *International Journal of Disaster Risk Reduction*, **2**, 84-94.

Figueroa, J., 2008: The need to strengthen malaria control in the Caribbean in the era of HIV/AIDS. *West Indian Medical Journal*, **57(5)**, 425-426.

Fish, M.R., I.M. Cote, J.A. Horrocks, B. Mulligan, A.R. Watkinson, and A.P. Jones, 2008: Construction setback regulations and sea-level rise: mitigating sea turtle nesting beach loss. *Ocean and Coastal Management*, **51(4)**, 330-341.

Fletcher, C.H., C. Bochicchio, C. Conger, M. Engels, F. Feirstein, N. Frazer, C. Glenn, R.W. Grigg, E.E. Grossman, and J.N. Harvey, 2008: Geology of Hawaii reefs. In: *Coral Reefs of the USA* [Riegl, B.M. and R.E. Dodge (eds.)]. Coral Reefs of the World, Vol. 1, Springer Science, Dordrecht, Netherlands, pp. 435-487.

Forbes, D.L., T.S. James, M. Sutherland, and S.E. Nichols, 2013: Physical basis of coastal adaptation on tropical small islands. *Sustainability Science*, **8(3)**, 327-344.

Ford, M., 2012: Shoreline changes on an urban atoll in the central Pacific Ocean: Majuro Atoll, Marshall Islands. *Journal of Coastal Research*, **28(1)**, 11-22.

Ford, M., 2013: Shoreline changes interpreted from multi-temporal aerial photographs and high resolution satellite images: Wotje Atoll, Marshall Islands. *Remote Sensing of Environment*, **135**, 130-140.

Forster, J., P.W. Schuhmann, I.R. Lake, A.R. Watkinson, and J.A. Gill, 2012: The influence of hurricane risk on tourist destination choice in the Caribbean. *Climatic Change*, **114(3-4)**, 745-768.

Fox, J.C., C.K. Yosi, P. Nimiago, F. Oavika, J.N. Pokana, K. Lavong, and R.J. Keenan, 2010: Assessment of aboveground carbon in primary and selectively harvested tropical forest in Papua New Guinea. *Biotropica*, **42(4)**, 410-419.

Freed, L.A., R.L. Cann, M.L. Goff, W.A. Kuntz, and G.R. Bodner, 2005: Increase in avian malaria at upper elevations in Hawaii. *The Condor*, **107(4)**, 753-764.

Frieler, K., M. Meinshausen, A. Golly, M. Mengel, K. Lebek, S.D. Donner, and O. Hoegh-Guldberg, 2013: Limiting global warming to 2°C is unlikely to save most coral reefs. *Nature Climate Change*, **3**, 165-170.

Gaigher, R., M. Samways, J. Henwood, and K. Jolliffe, 2011: Impact of a mutualism between an invasive ant and honeydew-producing insects on a functionally important tree on a tropical island. *Biological Invasions*, **13(8)**, 1717-1721.

Gamble, D.W., D. Campbell, T.L. Allen, D. Barker, S. Curtis, D. McGregor, and J. Popke, 2010: Climate change, drought, and Jamaican agriculture: local knowledge and the climate record. *Annals of the Association of American Geographers*, **100(4)**, 880-893.

Game, E.T., G. Lipsett-Moore, R. Hamilton, N. Peterson, J. Kereseka, W. Atu, M. Watts, and H. Possingham, 2011: Informed opportunism for conservation planning in the Solomon Islands. *Conservation Letters*, **4(1)**, 38-46.

Garrison, V., W. Foreman, S. Genualdi, D. Griffin, C. Kellogg, M. Majewski, A. Mohammed, A. Ramsubhag, E. Shinn, and S. Simonich, 2006: Saharan dust – a carrier of persistent organic pollutants, metals and microbes to the Caribbean? *Revista de Biología Tropical*, **54(3 Suppl.)**, 9-21.

Gemenne, F., 2011: Climate-induced population displacements in a 4°C world. *Philosophical Transactions of the Royal Society A*, **369(1934)**, 182-195.

Gero, A., K. Méheux, and D. Dominey-Howes, 2011: Integrating community based disaster risk reduction and climate change adaptation: examples from the Pacific. *Natural Hazards and Earth System Sciences*, **11(1)**, 101-113.

29

Gillespie, T.W., J. Chu, and S. Pau, 2008: Non-native plant invasion of the Hawaiian Islands. *Geography Compass*, **2(5)**, 1241-1265.
Gilman, E.L., J. Ellison, N.C. Duke, and C. Field, 2008: Threats to mangroves from climate change and adaptation options: a review. *Aquatic Botany*, **89(2)**, 237-250.
Gilmour, J.P., L.D. Smith, A.J. Heyward, A.H. Baird, and M.S. Pratchett, 2013: Recovery of an isolated coral reef system following severe disturbance. *Science*, **340(6128)**, 69-71.
Goodman, J., J. Maschinski, P. Hughes, J. McAuliffe, J. Roncal, D. Powell, and L.O. Sternberg, 2012: Differential response to soil salinity in endangered key tree cactus: implications for survival in a changing climate. *PLoS ONE*, **7(3)**, e32528, doi:10.1371/journal.pone.0032528.
Gordon-Clark, M., 2012: Paradise lost? Pacific island archives threatened by climate change. *Archival Science*, **12(1)**, 51-67.
Gössling, S. and K.P. Schumacher, 2010: Implementing carbon neutral destination policies: issues from the Seychelles. *Journal of Sustainable Tourism*, **18(3)**, 377-391.
Gössling, S., O. Lindén, J. Helmersson, J. Liljenberg, and S. Quarm, 2012a: Diving and global environmental change: a Mauritius case study. In: *New Frontiers in Marine Tourism: Diving Experiences, Management and Sustainability* [Garrod, B. and S. Gössling (eds.)]. Elsevier, Amsterdam, Netherlands, 67 pp.
Gössling, S., P. Peeters, C.M. Hall, J.-P. Ceron, G. Dubois, L.V. Lehmann, and D. Scott, 2012b: Tourism and water use: supply, demand, and security. An international review. *Tourism Management*, **33(1)**, 1-15.
Gravelle, G. and N. Mimura, 2008: Vulnerability assessment of sea-level rise in Viti Levu, Fiji Islands. *Sustainability Science*, **3(2)**, 171-180.
Greaver, T.L. and L.S.L. Sternberg, 2010: Decreased precipitation exacerbates the effects of sea level on coastal dune ecosystems in open ocean islands. *Global Change Biology*, **16(6)**, 1860-1869.
Green, S.J., J.L. Akins, and I.M. Côté, 2011: Foraging behaviour and prey consumption in the Indo-Pacific lionfish on Bahamian coral reefs. *Marine Ecology Progress Series*, **433**, 159-167.
Green, S.J., J.L. Akins, A. Maljković, and I.M. Côté, 2012: Invasive lionfish drive Atlantic coral reef fish declines. *PLoS ONE*, **7(3)**, e32596, doi:10.1371/journal.pone.0032596.
Griffin, D.W., 2007: Atmospheric movement of microorganisms in clouds of desert dust and implications for human health. *Clinical Microbiology Reviews*, **20(3)**, 459-477.
Gritti, E., B. Smith, and M. Sykes, 2006: Vulnerability of Mediterranean Basin ecosystems to climate change and invasion by exotic plant species. *Journal of Biogeography*, **33(1)**, 145-157.
Guillaumont, P., 2010: Assessing the economic vulnerability of small island developing states and the least developed countries. *The Journal of Development Studies*, **46(5)**, 828-854.
Haigh, I.D., M. Eliot, and C. Pattiaratchi, 2011: Global influences of the 18.61 year nodal cycle and 8.85 year cycle of lunar perigee on high tidal levels. *Journal of Geophysical Research: Oceans*, **116(C6)**, C06025, doi:10.1029/2010JC006645.
Hansen, L., J. Hoffman, C. Drews, and E. Mielbrecht, 2010: Designing climate-smart conservation: guidance and case studies. *Conservation Biology*, **24(1)**, 63-69.
Harangozo, S.A., 1992: Flooding in the Maldives and its implications for the global sea level rise debate. In: *Sea Level Changes: Determination and Effects* [Woodworth, P.L., D.T. Pugh, J.G. DeRonde, R.G. Warrick, and J. Hannah (eds.)]. Geophysical Monograph Series, 69, International Union of Geodesy and Geophysics and the American Geophysical Union, Washington, DC, USA, pp. 95-99.
Hardman, E.R., N.S. Stampfli, L. Hunt, S. Perrine, A. Perry, and J.S.J. Raffin, 2007: The impacts of coral bleaching in Rodrigues, Western Indian Ocean. *Atoll Research Bulletin*, **555**, 1-10.
Hare, W.L., W. Cramer, M. Schaeffer, A. Battaglini, and C.C. Jaeger, 2011: Climate hotspots: key vulnerable regions, climate change and limits to warming. *Regional Environmental Change*, **11(1 Suppl.)**, S1-S13.
Harmsen, E.W., N.L. Miller, N.J. Schlegel, and J.E. Gonzalez, 2009: Seasonal climate change impacts on evapotranspiration, precipitation deficit and crop yield in Puerto Rico. *Agricultural Water Management*, **96(7)**, 1085-1095.
Harp, E.L., M.E. Reid, J.P. McKenna, and J.A. Michael, 2009: Mapping of hazard from rainfall-triggered landslides in developing countries: examples from Honduras and Micronesia. *Engineering Geology*, **104(3-4)**, 295-311.
Harris, A., G. Manahira, A. Sheppard, C. Gough, and C. Sheppard, 2010: Demise of Madagascar's once great barrier reef: changes in coral reef conditions over 40 years. *Atoll Research Bulletin*, **574**, 1-16.
Hay, J.E., 2013: Small island developing states: coastal systems, global change and sustainability. *Sustainability Science*, **8(3)**, 309-326.
Hay, J.E. and N. Mimura, 2013: Vulnerability, risk and adaptation assessment methods in the Pacific Islands region: past approaches, and considerations for the future. *Sustainability Science*, **8(3)**, 391-405.
Hay, S.I., C.A. Guerra, P.W. Gething, A.P. Patil, A.J. Tatem, A.M. Noor, C.W. Kabaria, B.H. Manh, I.R.F. Elyazar, S. Brooker, D.L. Smith, R.A. Moyeed, and R.W. Snow, 2009: A world malaria map: *Plasmodium falciparum* endemicity in 2007. *PLoS Medicine*, **6(3)**, e1000048, doi:10.1371/journal.pmed.1000048.
Heger, M., A. Julca, and O. Paddison, 2008: Analysing the impact of natural hazards in small economies: the Caribbean case. UNU-WIDER Research Paper No. 2008/25, United Nations, University World Institute for Development Economics Research (UNU-WIDER), Helsinki, Finland, 27 pp.
Heltberg, R., P.B. Siegel, and S.L. Jorgensen, 2009: Addressing human vulnerability to climate change: toward a 'no-regrets' approach. *Global Environmental Change*, **19(1)**, 89-99.
Hemer, M.A., Y. Fan, N. Mori, A. Semedo, and X.L. Wang, 2013: Projected changes in wave climate from multi-model ensemble. *Nature Climate Change*, **3(5)**, 471-476.
Herrmann-Storck, C., D. Postic, I. Lamaury, and J.M. Perez, 2008: Changes in epidemiology of leptospirosis in 2003-2004, a two El Niño – Southern Oscillation period, Guadeloupe archipelago, French West Indies. *Epidemiology and Infection*, **136(10)**, 1407-1415.
Herweijer, C., N. Ranger, and R.E.T. Ward, 2009: Adaptation to climate change: threats and opportunities for the insurance industry. *The Geneva Papers on Risk and Insurance – Issues and Practice*, **34(3)**, 360-380.
Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F.H. Sale, A. Dubi, and M.E. Hatziolos, 2007: Coral reefs under rapid climate change and ocean acidification. *Science*, **318(5857)**, 1737-1742.
Hoeke, R.K., K.L. McInnes, J. Kruger, R. McNaught, J. Hunter, and S. Smithers, 2013: Widespread inundation of Pacific islands by distant-source wind-waves. *Global Environmental Change*, **108**, 128-138.
Hornidge, A. and F. Scholtes, 2011: Climate change and everyday life in Toineke Village, West Timor: uncertainties, knowledge and adaptation. *Sociologus*, **61(2)**, 151-175.
Houston, J.R., 2002: The economic value of beaches – a 2002 update. *Shore and Beach*, **70(1)**, 9-12.
Howard, G., K. Charles, K. Pond, A. Brookshaw, R. Hossain, and J. Bartram, 2010: Securing 2020 vision for 2030: climate change and ensuring resilience in water and sanitation services. *Journal of Water and Climate Change*, **1(1)**, 2-16.
Hughes, S., A. Yau, L. Max, N. Petrovic, F. Davenport, M. Marshall, T.R. McClanahan, E.H. Allison, and J.E. Cinner, 2012: A framework to assess national level vulnerability from the perspective of food security: the case of coral reef fisheries. *Environmental Science & Policy*, **23**, 95-108.
Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nyström, S.R. Palumbi, J.M. Pandolfi, B. Rosen, and J. Roughgarden, 2003: Climate change, human impacts, and the resilience of coral reefs. *Science*, **301(5635)**, 929-933.
Hübner, A. and S. Gössling, 2012: Tourist perceptions of extreme weather events in Martinique. *Journal of Destination Marketing & Management*, **1(1-2)**, 47-55.
Idjadi, J.A., R.N. Haring, and W.F. Precht, 2010: Recovery of the sea urchin *Diadema antillarum* promotes scleractinian coral growth and survivorship on shallow Jamaican reefs. *Marine Ecology Progress Series*, **403**, 91-100.
IPCC, 2007: *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 851 pp.
IPCC, 2011: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, and C. von Stechow (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 1075 pp.
Jarvis, R., 2010: Sinking nations and climate change adaptation strategies. *Seattle Journal of Social Justice*, **9(1)**, 447-486.
Joe, S.M. and C.C. Daehler, 2008: Invasive slugs as under-appreciated obstacles to rare plant restoration: evidence from the Hawaiian Islands. *Biological Invasions*, **10(2)**, 245-255.

Jones, G.P., M.I. McCormick, M. Srinivasan, and J.V. Eagle, 2004: Coral decline threatens fish biodiversity in marine reserves. *Proceedings of the National Academy of Sciences of the United States of America*, **101(21)**, 8251-8253.

Jones, P., 2005: Managing urban development in the Pacific. *Australian Planner*, **42(1)**, 39-46.

Jump, A.S., T.-J. Huang, and C.-H. Chou, 2012: Rapid altitudinal migration of mountain plants in Taiwan and its implications for high altitude biodiversity. *Ecography*, **35**, 204-210.

Jury, M.R. and A. Winter, 2010: Warming of an elevated layer over the Caribbean. *Climatic Change*, **99(1-2)**, 247-259.

Kaldellis, J.K., 2008: Integrated electrification solution for autonomous electrical networks on the basis of RES and energy storage configurations. *Energy Conversion and Management*, **49(12)**, 3708-3720.

Kaldellis, J.K., D. Zafirakis, E.L. Kaldelli, and K. Kavadias, 2009: Cost benefit analysis of a photovoltaic-energy storage electrification solution for remote islands. *Renewable Energy*, **34(5)**, 1299-1311.

Keener, V., J.J. Marra, M.L. Finucane, D. Spooner, and M.H. Smith, 2012: *Climate Change and Pacific Islands: Indicators and Impacts: Report for the 2012 Pacific Islands Regional Climate Assessment.* Island Press, Washington, DC, USA, 170 pp.

Kelman, I., 2010: Introduction to climate, disasters and international development. *Journal of International Development*, **22(2)**, 208-217.

Kelman, I. and J. West, 2009: Climate change and Small Island Developing States: a critical review. *Ecological and Environmental Anthropology*, **5(1)**, 1-16.

Kelman, I., J. Lewis, J.C. Gaillard, and J. Mercer, 2011: Participatory action research for dealing with disasters on islands. *Island Studies Journal*, **6(1)**, 59-86.

Kenis, M., M.-A. Auger-Rozenberg, A. Roques, L. Timms, C. Péré, M.J.W. Cock, J. Settele, S. Augustin, and C. Lopez-Vaamonde, 2009: Ecological effects of invasive alien insects. *Biological Invasions*, **11(1)**, 21-45.

Kingsford, R., J. Watson, C. Lundquist, O. Venter, L. Hughes, E. Johnston, J. Atherton, M. Gawel, D. Keith, B. Mackey, C. Morley, H.B. Possingham, B. Raynor, H.F. Recher, and K.A. Wilson, 2009: Major conservation policy issues for biodiversity in Oceania. *Conservation Biology*, **23(4)**, 834-840.

Klein, R., S. Ericksen, L. Ness, A. Hammill, T. Tanner, C. Robledo, and K. O'Brien, 2007: Portfolio screening to support the mainstreaming of adaptation to climate change into development assistance. *Climatic Change*, **84(1)**, 23-44.

Klint, L.M., M. Jiang, A. Law, T. Delacy, S. Filep, E. Calgaro, D. Dominey-Howes, and D. Harrison, 2012: Dive tourism in Luganville, Vanuatu: shocks, stressors, and vulnerability to climate change. *Tourism in Marine Environments*, **8(1-2)**, 91-109.

Koh, B.K., L.C. Ng, Y. Kita, C.S. Tang, L.W. Ang, K.Y. Wong, L. James, and K.T. Goh, 2008: The 2005 dengue epidemic in Singapore: epidemiology, prevention and control. *Annals, of the Academy of Medicine, Singapore (AAMS)*, **37(7)**, 538-545.

Kolmannskog, V. and L. Trebbi, 2010: Climate change, natural disasters and displacement: a multi-track approach to filling the protection gaps. *International Review of the Red Cross*, **92(879)**, 713-730.

Komar, P.D. and J.C. Allan, 2008: Increasing hurricane-generated wave heights along the US East Coast and their climate controls. *Journal of Coastal Research*, **24(2)**, 479-488.

Krajačić, G., N. Duić, B.V. Mathiesen, and M.d.G. Carvalho, 2010: Smart energy storages for integration of renewables in 100% independent energy systems. (PRES 2010, 13th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, August 28-September 1, 2010, Prague, Czech Republic.) *Chemical Engineering Transactions*, **21**, 391-396, doi:10.3303/CET1021066.

Krauss, K.W., J.A. Allen, and D.R. Cahoon, 2003: Differential rates of vertical accretion and elevation change among aerial root types in Micronesian mangrove forests. *Estuarine, Coastal and Shelf Science*, **56(2)**, 251-259.

Krauss, K.W., D.R. Cahoon, J.A. Allen, K.C. Ewel, J.C. Lynch, and N. Cormier, 2010: Surface elevation change and susceptibility of different mangrove zones to sea-level rise on Pacific high islands of Micronesia. *Ecosystems*, **13(1)**, 129-143.

Kravchenko, S., 2008: Right to carbon or right to life: human rights approaches to climate change. *Vermont Journal of Environmental Law*, **9(3)**, 513-547.

Krishnamurthy, P.K., 2012: Disaster-induced migration: assessing the impact of extreme weather events on livelihoods. *Environmental Hazards*, **11(2)**, 96-111.

Krushelnycky, P.D., L.L. Loope, T.W. Giambelluca, F. Starr, K. Starr, D.R. Drake, A.D. Taylor, and R.H. Robichaux, 2013: Climate-associated population declines reverse recovery and threaten future of an iconic high-elevation plant. *Global Change Biology*, **19(3)**, 911-922.

Kueffer, C., C.C. Daehler, C.W. Torres-Santana, C. Lavergne, J.-Y. Meyer, R. Otto, and L. Silva, 2010: A global comparison of plant invasions on oceanic islands. *Perspectives in Plant Ecology Evolution and Systematics*, **12(2)**, 145-161.

Kumar, V.S., V.R. Babu, M. Babu, G. Dhinakaran, and G. Rajamanickam, 2008: Assessment of storm surge disaster potential for the Andaman Islands. *Journal of Coastal Research*, **24(2B)**, 171-177.

Kuruppu, N., 2009: Adapting water resources to climate change in Kiribati: the importance of cultural values and meanings. *Environmental Science & Policy*, **12(7)**, 799-809.

Kuruppu, N. and D. Liverman, 2011: Mental preparation for climate adaptation: the role of cognition and culture in enhancing adaptive capacity of water management in Kiribati. *Global Environmental Change*, **21(2)**, 657-669.

Laczko, F. and C. Aghazarm, 2009: *Migration, Environment and Climate Change: Assessing the Evidence.* International Organization for Migration (IOM), Geneva, Switzerland, 441 pp.

Lata, S. and P. Nunn, 2012: Misperceptions of climate-change risk as barriers to climate-change adaptation: a case study from the Rewa Delta, Fiji. *Climatic Change*, **110(1-2)**, 169-186.

Lauer, M. and S. Aswani, 2010: Indigenous knowledge and long-term ecological change: detection, interpretation, and responses to changing ecological conditions in Pacific Island Communities. *Environmental Management*, **45(5)**, 985-997.

Lazrus, H., 2012: Sea change: island communities and climate change. *Annual Review of Anthropology*, **41(1)**, 285-301.

Le Masson, V. and I. Kelman, 2011: Disaster risk reduction on non-sovereign islands: La Réunion and Mayotte, France. *Natural Hazards*, **56(1)**, 251-273.

Le Roux, J.J., A.M. Wieczorek, and J.-Y. Meyer, 2008: Genetic diversity and structure of the invasive tree *Miconia calvescens* in Pacific islands. *Diversity and Distributions*, **14(6)**, 935-948.

Le Roux, P.C., M.A. McGeoch, M.J. Nyakatya, and S.L. Chown, 2005: Effects of a short-term climate change experiment on a sub-Antarctic keystone plant species. *Global Change Biology*, **11(10)**, 1628-1639.

Lefale, P.F., 2010: *Ua 'afa le Aso* Stormy weather today: traditional ecological knowledge of weather and climate. The Samoa experience. *Climatic Change*, **100(2)**, 317-335.

Lesser, M.P. and M. Slattery, 2011: Phase shift to algal dominated communities at mesophotic depths associated with lionfish (*Pterois volitans*) invasion on a Bahamian coral reef. *Biological Invasions*, **13(8)**, 1855-1868.

Lessios, H.A., 1988: Mass mortality of *Diadema antillarum* in the Caribbean: what have we learned? *Annual Review of Ecology and Systematics*, **19(1)**, 371-393.

Lessios, H.A., 1995: *Diadema antillarum* 10 years after mass mortality: still rare, despite help from a competitor. *Proceedings of the Royal Society B*, **259(1356)**, 331-337.

Lilleør, H.B. and K. Van den Broeck, 2011: Economic drivers of migration and climate change in LDCs. *Global Environmental Change*, **21(1 Suppl.)**, S70-S81.

Limalevu, L., B. Aalsbersberg, P. Dumaru, and T. Weir, 2010: Adaptation on a small island. *Tiempo*, **77**, 16-19.

Linnerooth-Bayer, J. and R. Mechler, 2009: *Insurance against Losses from Natural Disasters in Developing Countries.* ST/ESA/2009/DWP/85, DESA Working Paper No. 85, United Nations Department of Economic and Social Affairs (UN DESA), New York, NY, USA, 35 pp.

Linnerooth-Bayer, J., R. Mechler, and S. Hochrainer, 2011: Insurance against losses from natural disasters in developing countries. Evidence, gaps and the way forward. *Journal of Integrated Disaster Risk Management (IDRiM)*, **1(1)**, 59-81.

Llewellyn, L.E., 2010: Revisiting the association between sea surface temperature and the epidemiology of fish poisoning in the South Pacific: reassessing the link between ciguatera and climate change. *Toxicon*, **56(5)**, 691-697.

Locke, J.T., 2009: Climate change-induced migration in the Pacific region: sudden crisis and long-term developments. *The Geographical Journal*, **175(3)**, 171-180.

López-Marrero, T., 2010: An integrative approach to study and promote natural hazards adaptive capacity: a case study of two flood-prone communities in Puerto Rico. *Geographical Journal*, **176(2)**, 150-163.

López-Marrero, T. and B. Yarnal, 2010: Putting adaptive capacity into the context of people's lives: a case study of two flood-prone communities in Puerto Rico. *Natural Hazards*, **52(2)**, 277-297.

López-Villarrubia, E., F. Ballester, C. Iñiguez, and N. Peral, 2010: Air pollution and mortality in the Canary Islands: a time-series analysis. *Environmental Health*, **9**, 8, doi:10.1186/1476-069X-9-8.

Loughry, M. and J. McAdam, 2008: Kiribati – relocation and adaptation. *Forced Migration Review*, **31**, 51-52.

29

Lovell, S., 2011: Health governance and the impact of climate change on Pacific small island developing states. *IHDP Update: Magazine of the International Human Dimensions Programme on Global Environmental Change*, **2011(1)**, 50-55.

Lozano, M.A., 2006: Riesgos catastróficos en las Islas Canarias. Una visión geográfica [Catastrophic hazards in the Canary Islands. A geographic vision]. *Anales de Geografía*, **26**, 167-194 (in Spanish).

Lo-Yat, A., S.D. Simpson, M. Meekan, D. Lecchini, E. Martinez, and R. Galzin, 2011: Extreme climatic events reduce ocean productivity and larval supply in a tropical reef ecosystem. *Global Change Biology*, **17(4)**, 1695-1702.

Maina, J., T.R. McClanahan, V. Venus, M. Ateweberhan, and J. Madin, 2011: Global gradients of coral exposure to environmental stresses and implications for local management. *PLoS ONE*, **6(8)**, e23064, doi:10.1371/journal.pone.0023064.

Maldives Department of Meteorology, 2007: *The Unusually Strong Tidal Waves Hit Maldives*, *15-18 May.* Department of Meteorology, Malé, Republic of Maldives, 15 pp.

Maniku, H.A., 1990: *Changes in the Topography of the Maldives.* Forum of Writers on Environment (Maldives), Malé, Republic of Maldives, 91 pp.

Marba, N. and C.M. Duarte, 2010: Mediterranean warming triggers seagrass (*Posidonia oceanica*) shoot mortality. *Global Change Biology*, **16(8)**, 2366-2375.

Martens, P., R.S. Kovats, S. Nijof, P. de Vries, M.T.J. Livermore, D.J. Bradley, J. Cox, and A.J. McMichael, 1999: Climate change and future populations at risk of malaria. *Global Environmental Change*, **9(1 Suppl.)**, S89-S107.

Martins, P., J. Rosado-Pinto, M. do Céu Teixeira, N. Neuparth, O. Silva, H. Tavares, J.L. Spencer, D. Mascarenhas, A.L. Papoila, N. Khaltaev, and I. Annesi-Maesano, 2009: Under-report and underdiagnosis of chronic respiratory diseases in an African country. *Allergy*, **64(7)**, 1061-1067.

Maunsell Australia Pty Ltd., 2009: *Climate Change Risk Assessment for the Australian Indian Ocean Territories: Cocos (Keeling) Islands and Christmas Island.* Document No. 60046031-FD, Prepared for the Commonwealth Attorney-General's Department by P. Mackay, G. Prudent-Richard, and L. Hoekstra-Fokkink, Maunsell Australia Pty Ltd., in association with the Commonwealth Scientific and Industrial Research Organization (CSIRO) and Coastal Zone Management (CZM) Pty Ltd., Canberra, ACT, Australia, 93 pp.

McClanahan, T., J. Cinner, J. Maina, N. Graham, T. Daw, S. Stead, A. Wamukota, K. Brown, M. Ateweberhan, and V. Venus, 2008: Conservation action in a changing climate. *Conservation Letters*, **1(2)**, 53-59.

McGranahan, G., D. Balk, and B. Anderson, 2007: The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization*, **19(1)**, 17-37.

McGray, H., A. Hammil, and R. Bradley, 2007: *Weathering the Storm: Options for Framing Adaptation and Development.* World Resources Institute (WRI), Washington, DC, USA, 57 pp.

McKee, K.L., D.R. Cahoon, and I.C. Feller, 2007: Caribbean mangroves adjust to rising sea level through biotic controls on change in soil elevation. *Global Ecology and Biogeography*, **16(5)**, 545-556, doi:10.1111/j.1466-8238.2007.00317.x.

McLeman, R.A., 2011: Settlement abandonment in the context of global environmental change. *Global Environmental Change*, **21(1 Suppl.)**, S108-S120.

McLeman, R.A. and L.M. Hunter, 2010: Migration in the context of vulnerability and adaptation to climate change: insights from analogues. *Wiley Interdisciplinary Reviews: Climate Change*, **1(3)**, 450-461.

McLeod, E., R. Salm, A. Green, and J. Almany, 2009: Designing marine protected area networks to address the impacts of climate change. *Frontiers in Ecology and the Environment*, **7(7)**, 362-370.

McMichael, A.J. and E. Lindgren, 2011: Climate change: present and future risks to health, and necessary responses. *Journal of Internal Medicine*, **270(5)**, 401-413.

McMichael, C., J. Barnett, and A.J. McMichael, 2012: An ill wind? Climate change, migration, and health. *Environmental Health Perspectives*, **120(5)**, 646-654.

McNamara, K.E. and C. Gibson, 2009: 'We do not want to leave our land': Pacific ambassadors at the United Nations resist the category of 'climate refugees'. *Geoforum*, **40(3)**, 475-483.

McNamara, K.E. and R. Westoby, 2011: Local knowledge and climate change adaptation on Erub Island, Torres Strait. *Local Environment*, **16(9)**, 887-901.

Mercer, J., D. Dominey-Howes, I. Kelman, and K. Lloyd, 2007: The potential for combining indigenous and western knowledge in reducing vulnerability to environmental hazards in small island developing states. *Environmental Hazards*, **7(4)**, 245-256.

Merrifield, M., S. Merrifield, and G. Mitchum, 2009: An anomalous recent acceleration of global sea level rise. *Journal of Climate*, **22(21)**, 5772-5781.

Mertz, O., K. Halsnæs, J.E. Olesen, and K. Rasmussen, 2009: Adaptation to climate change in developing countries. *Environmental Management*, **43(5)**, 743-752.

Mertz, O., T.B. Bruun, B. Fog, K. Rasmussen, and J. Agergaard, 2010: Sustainable land use in Tikopia: food production and consumption in an isolated agricultural system. *Singapore Journal of Tropical Geography*, **31(1)**, 10-26.

Meyer III, W.M., K.A. Hayes, and A.L. Meyer, 2008: Giant African snail, *Achatina fulica*, as a snail predator. *American Malacological Bulletin*, **24(1-2)**, 117-119.

Meyssignac, B., M. Becker, W. Llovel, and A. Cazenave, 2012: An assessment of two-dimensional past sea level recontructions over 1950-2009 based on tide-gauge data and different input sea level grids. *Surveys in Geophysics*, **33(5)**, 945-972.

Michon, P., J.L. Cole-Tobian, E. Dabod, S. Schoepflin, J. Igu, M. Susapu, N. Tarongka, P.A. Zimmerman, J.C. Reeder, and J.G. Beeson, 2007: The risk of malarial infections and disease in Papua New Guinean children. *The American Journal of Tropical Medicine and Hygiene*, **76(6)**, 997-1008.

Middleton, N., P. Yiallouros, S. Kleanthous, O. Kolokotroni, J. Schwartz, D.W. Dockery, P. Demokritou, and P. Koutrakis, 2008: A 10-year time-series analysis of respiratory and cardiovascular morbidity in Nicosia, Cyprus: the effect of short-term changes in air pollution and dust storms. *Environmental Health*, **7**, 39, doi:10.1186/1476-069X-7-39.

Miller, J., E. Muller, C. Rogers, R. Waara, A. Atkinson, K.R.T. Whelan, M. Patterson, and B. Witcher, 2009: Coral disease following massive bleaching in 2005 causes 60% decline in coral cover on reefs in the US Virgin Islands. *Coral Reefs*, **28(4)**, 925-937.

Miller, S., T. Brewer, and N. Harris, 2009: Rainfall thresholding and susceptibility assessment of rainfall-induced landslides: application to landslide management in St. Thomas, Jamaica. *Bulletin of Engineering Geology and the Environment*, **68(4)**, 539-550.

Mills, M., R.L. Pressey, R. Weeks, S. Foale, and N.C. Ban, 2010: A mismatch of scales: challenges in planning for implementation of marine protected areas in the Coral Triangle. *Conservation Letters*, **3(5)**, 291-303.

Mimura, N., L.A. Nurse, R.F. McLean, J. Agard, L. Briguglio, P. Lefale, R. Payet, and G. Sem, 2007: Small islands. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 687-716.

Moglia, M., P. Perez, and S. Burn, 2008a: Urbanization and water development in the Pacific Islands. *Development*, **51(1)**, 49-55.

Moglia, M., P. Perez, and S. Burn, 2008b: Water troubles in a Pacific atoll town. *Water Policy*, **10(6)**, 613-637.

Mohan, A., A. Cumberbatch, A. Adesiyun, and D.D. Chadee, 2009: Epidemiology of human leptospirosis in Trinidad and Tobago, 1996-2000: a retrospective study. *Acta Tropica*, **112(3)**, 260-265.

Mohanty, M., 2012: New renewable energy sources, green energy development and climate change: implications to Pacific Island countries. *Management of Environmental Quality: An International Journal*, **23(3)**, 264-274.

Monteil, M., 2008: Saharan dust clouds and human health in the English-speaking Caribbean: what we know and don't know. *Environmental Geochemistry and Health*, **30(4)**, 339-343.

Monteil, M. and R. Antoine, 2009: African dust and asthma in the Caribbean: medical and statistical perspectives. *International Journal of Biometeorology*, **53(5)**, 379-381.

Moore, W.R., 2010: The impact of climate change on Caribbean tourism demand. *Current Issues in Tourism*, **13(5)**, 495-505.

Moreno, A. and S. Becken, 2009: A climate change vulnerability assessment methodology for coastal tourism. *Journal of Sustainable Tourism*, **17(4)**, 473-488.

Morrison, K., P.A. Prieto, A.C. Domínguez, D. Waltner-Toews, and J. FitzGibbon, 2008: Ciguatera fish poisoning in La Habana, Cuba: a study of local social-ecological resilience. *Ecohealth*, **5(3)**, 346-359.

Mortreux, C. and J. Barnett, 2009: Climate change, migration and adaptation in Funafuti, Tuvalu. *Global Environmental Change*, **19(1)**, 105-112.

Moss, R.H., J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. van Vuuren, T.R. Carter, S. Emori, M. Kainuma, T. Kram, G.A. Meehl, J.F.B. Mitchell, N. Nakicenovic, K. Riahi, S.J. Smith, R.J. Stouffer, A.M. Thomson, J.P. Weyant, and T.J. Wilbanks, 2010: The next generation of scenarios for climate change research and assessment. *Nature*, **463(7282)**, 747-756.

Munday, P.L., J.M. Leis, J.M. Lough, C.B. Paris, M.J. Kingsford, M.L. Berumen, and J. Lambrechts, 2009: Climate change and coral reef connectivity. *Coral Reefs*, **28(2)**, 379-395.

Mycoo, M., 2007: Diagnosis of Trinidad's water problems (mid-1980s to mid-1990s). *Water Policy*, **9(1)**, 73-86.

Mycoo, M., 2011: Natural hazard risk reduction: making St. Lucia safe in an era of increased hurricanes and associated events. *Natural Hazards Review*, **12(1)**, 37-45.

Mycoo, M. and A. Chadwick, 2012: Adaptation to climate change: the coastal zone of Barbados. *Proceedings of the Institution of Civil Engineers (ICE) - Maritime Engineering*, **165(4)**, 159-168.

Myers, N., 2002: Environmental refugees: a growing phenomenon of the 21st century. *Philosophical Transactions of the Royal Society B*, **357(1420)**, 609-613.

Nelson, D.R., 2011: Adaptation and resilience: responding to a changing climate. *Wiley Interdisciplinary Reviews: Climate Change*, **2(1)**, 113-120.

Nicholls, R.J. and A. Cazenave, 2010: Sea-level rise and its impact on coastal zones. *Science*, **328(5985)**, 1517-1520.

Nicholls, R.J. and R.S.J. Tol, 2006: Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century. *Philosophical Transactions of the Royal Society A*, **364(1841)**, 1073-1095.

Nicholls, R.J., N. Marinova, J.A. Lowe, S. Brown, P. Vellinga, D. de Gusmao, J. Hinkel, and R.S.J. Tol, 2011: Sea-level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. *Philosophical Transactions of the Royal Society A*, **369(1934)**, 161-181.

Nicoll, K.A., R.G. Harrison, and Z. Ulanowski, 2011: Observation of Saharan dust electrification. *Environmental Research Letters*, **6(1)**, 014001, doi:10.1088/1748-9326/6/1/014001.

Novelo-Casanova, D.A. and G. Suarez, 2010: Natural and man-made hazards in the Cayman Islands. *Natural Hazards*, **55(2)**, 441-466.

Nunn, P.D., 2007: *Climate, Environment, and Society in the Pacific during the Last Millennium*. Developments in Earth and Environmental Sciences, Vol. 6, Elsevier, Amsterdam, Netherlands, 316 pp.

Nunn, P.D., 2009: Responding to the challenges of climate change in the Pacific Islands: management and technological imperatives. *Climate Research*, **40(2-3)**, 211-231.

Nunn, P.D., W. Aalbersberg, S. Lata, and M. Gwilliam, 2013: Beyond the core: community governance for climate-change adaptation in peripheral parts of Pacific Island Countries. *Regional Environmental Change* (in press), doi: 10.1007/s10113-013-0486-7.

Nurse, L.A., G. Sem, J.E. Hay, A.G. Suarez, P.P. Wong, L. Briguglio, and S. Ragoonaden, 2001: Small island states. In: *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment of the Intergovernmental Panel on Climate Change* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 843-876.

OECS, 2004: *Grenada: Macro-Socio-Economic Assessment of the Damages Caused by Hurricane Ivan, September 7th 2004.* Organisation of East Caribbean States (OECS), OECS Secretariat, Castries, St. Lucia, 126 pp.

Ogston, A.S. and M.E. Field, 2010: Predictions of turbidity due to enhanced sediment resuspension resulting from sea-level rise on a fringing coral reef: evidence from Molokai, Hawaii. *Journal of Coastal Research*, **26(6)**, 1027-1037.

Otero, P., S. Pérez, A. Alfonso, C. Vale, P. Rodríguez, Neide N. Gouveia, Nuno Gouveia, J. Delgado, P. Vale, M. Hirama, Y. Ishihara, J. Molgó, and L.M. Botana, 2010: First toxin profile of ciguateric fish in Madeira Arquipelago (Europe). *Analytical Chemistry*, **82(14)**, 6032-6039.

Oxenford, H.A., R. Roach, A. Brathwaite, L. Nurse, R. Goodridge, F. Hinds, K. Baldwin, and C. Finney, 2008: Quantitative observations of a major coral bleaching event in Barbados, southeastern Caribbean. *Climatic Change*, **87(3-4)**, 435-449.

Palanisamy, H., M. Becker, B. Meyssignac, O. Henry, and A. Cazenave, 2012: Regional sea level change and variability in the Caribbean Sea since 1950. *Journal of Geodetic Science*, **2(2)**, 125-133.

Pappas, G., P. Papadimitriou, V. Siozopoulou, L. Christou, and N. Akritidis, 2008: The globalization of leptospirosis: worldwide incidence trends. *International Journal of Infectious Diseases*, **12(4)**, 351-357.

Parham, P.E. and E. Michael, 2010: Modelling the effects of weather and climate change on malaria transmission. *Environmental Health Perspectives*, **118(5)**, 620-626.

Park, S., N. Marshall, E. Jakku, A. Dowd, S. Howden, E. Mendham, and A. Fleming, 2012: Informing adaptation responses to climate change through theories of transformation. *Global Environmental Change*, **22(1)**, 115-126.

Parks, B.C. and J.T. Roberts, 2006: Globalization, vulnerability to climate change, and perceived injustice. *Society and Natural Resources*, **19(4)**, 337-355.

Pascual, M., J.A. Ahumada, L.F. Chaves, X. Rodo, and M. Bouma, 2006: Malaria resurgence in the East African highlands: temperature trends revisited. *Proceedings of the National Academy of Sciences of the United States of America*, **103(15)**, 5829-5834.

Pauli, H., M. Gottfried, K. Reiter, C. Klettner, and G. Grabherr, 2007: Signals of range expansions and contractions of vascular plants in the high Alps: observations (1994-2004) at the GLORIA master site Schrankogel, Tyrol, Austria. *Global Change Biology*, **13(1)**, 147-156.

Payet, R. and W. Agricole, 2006: Climate change in the Seychelles: implications for water and coral reefs. *AMBIO: A Journal of the Human Environment*, **35(4)**, 182-189.

Peduzzi, P., H. Dao, C. Herold, and F. Mouton, 2009: Assessing global exposure and vulnerability towards natural hazards: the Disaster Risk Index. *Natural Hazards and Earth System Sciences*, **9(4)**, 1149-1159.

Pelling, M., 2011: Urban governance and disaster risk reduction in the Caribbean: the experiences of Oxfam GB. *Environment and Urbanization*, **23(2)**, 383-400.

Pelling, M. and J.I. Uitto, 2001: Small island developing states: natural disaster vulnerability and global change. *Global Environmental Change Part B: Environmental Hazards*, **3(2)**, 49-62.

Perch-Nielsen, S.L., 2010: The vulnerability of beach tourism to climate change – an index approach. *Climatic Change*, **100(3-4)**, 579-606.

Pérez-Arellano, J., O.P. Luzardo, A.P. Brito, M.H. Cabrera, M. Zumbado, C. Carranza, A. Angel-Moreno, R.W. Dickey, and L.D. Boada, 2005: Ciguatera fish poisoning, Canary Islands. *Emerging Infectious Diseases*, **11(12)**, 1981-1982.

Peters, G.P., R.M. Andrew, T. Boden, J.G. Canadell, P. Ciais, C. Le Quéré, G. Marland, M.R. Raupach, and C. Wilson, 2013: The challenge to keep global warming below 2°C. *Nature Climate Change*, **3**, 4-6.

Piskorska, M., G. Smith, and E. Weil, 2007: Bacteria associated with the coral *Echinopora lamellosa* (Esper 1795) in the Indian Ocean-Zanzibar Region. *African Journal of Environmental Science and Technology*, **1(5)**, 93-98.

Polidoro, B.A., K.E. Carpenter, L. Collins, N.C. Duke, A.M. Ellison, J.C. Ellison, E.J. Farnsworth, E.S. Fernando, K. Kathiresan, N.E. Koedam, S.R. Livingstone, T. Miyagi, G.E. Moore, V.N. Nam, J.E. Ong, J.H. Primavera, S.G. Salmo III, J.C. Sanciangco, S. Sukardjo, Y. Wang, and J.W.H. Yong, 2010: The loss of species: mangrove extinction risk and geographic areas of global concern. *PLoS ONE*, **5(4)**, e10095, doi:10.1371/journal.pone.0010095.

Polovina, J.J., J.P. Dunne, P.A. Woodworth, and E.A. Howell, 2011: Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming. *International Council for the Exploration of the Sea (ICES) Journal of Marine Science*, **68(6)**, 986-995.

Praene, J.P., M. David, F. Sinama, D. Morau, and O. Marc, 2012: Renewable energy: progressing towards a net zero energy island, the case of Reunion Island. *Renewable and Sustainable Energy Reviews*, **16(1)**, 426-442.

Prasad, B.C., 2008: Institutions, good governance and economic growth in the Pacific Island countries. *International Journal of Social Economics*, **35(12)**, 904-918.

Pratchett, M.S., S.K. Wilson, A.J. Graham, P.L. Munday, G.P. Jones, and N.V.C. Polunin, 2009: Coral bleaching and consequences for motile reef organisms: past, present and uncertain future effects. In: *Coral Bleaching: Patterns, Processes, Causes and Consequences* [van Oppen, M.J.H. and J.M. Lough (eds.)]. Ecological Studies, Vol. 205, Springer-Verlag, Berlin, Germany, pp. 139-158.

Prevatt, D., L. Dupigny-Giroux, and F. Masters, 2010: Engineering perspectives on reducing hurricane damage to housing in CARICOM Caribbean Islands. *Natural Hazards Review*, **11(4)**, 140-150.

Prospero, J.M., 2006: Case study: Saharan dust impacts and climate change. *Oceanography*, **19(2)**, 59-61.

Prospero, J.M. and P.J. Lamb, 2003: African droughts and dust transport to the Caribbean: climate change implications. *Science*, **302(5647)**, 1024-1027.

Prospero, J.M., E. Blades, G. Mathison, and R. Naidu, 2005: Interhemispheric transport of viable fungi and bacteria from Africa to the Caribbean with soil dust. *Aerobiologia*, **21(1)**, 1-19.

Prospero, J.M., E. Blades, R. Naidu, G. Mathison, H. Thani, and M. Lavoie, 2008: Relationship between African dust carried in the Atlantic trade winds and surges in pediatric asthma attendances in the Caribbean. *International Journal of Biometeorology*, **52(8)**, 823-832.

Pulwarty, R.S., L.A. Nurse, and U.O. Trotz, 2010: Caribbean Islands in a changing climate. *Environment: Science and Policy for Sustainable Development*, **52(6)**, 16-27.

Ralph, P.J., M.J. Durako, S. Enriquez, C.J. Collier, and M.A. Doblin, 2007: Impact of light limitation on seagrasses. *Journal of Experimental Marine Biology and Ecology*, **350(1-2)**, 176-193.

Rankey, E.C., 2011: Nature and stability of atoll island shorelines: Gilbert Island chain, Kiribati, equatorial Pacific. *Sedimentology*, **58(7)**, 1831-1859.

Rasmussen, K., W. May, T. Birk, M. Mataki, O. Mertz, and D. Yee, 2009: Climate change on three Polynesian outliers in the Solomon Islands: impacts, vulnerability and adaptation. *Geografisk Tidsskrift-Danish Journal of Geography*, **109(1)**, 1-13.

Rasmussen, K., W. May, T. Birk, M. Mataki, and O. Mertz, 2011: Prospects for climate change on three Polynesian outliers in Solomon Islands: exposure, sensitivity and adaptive capacity. *Geografisk Tidsskrift-Danish Journal of Geography*, **111(1)**, 43-57.

Rawlins, S.C., A. Hinds, and J.M. Rawlins, 2008: Malaria and its vectors in the Caribbean: the continuing challenge of the disease forty-five years after eradication from the islands. *West Indian Medical Journal*, **57(5)**, 462-469.

Reaser, J.K., L.A. Meyerson, Q. Cronk, M. De Poorter, L.G. Eldrege, E. Green, M. Kairo, P. Latasi, R.N. Mack, J. Mauremootoo, D. O'Dowd, W. Orapa, S. Sastroutomo, A. Saunders, C. Shine, S. Thrainsson, and L. Vaiutu, 2007: Ecological and socioeconomic impacts of invasive alien species in island ecosystems. *Environmental Conservation*, **34(02)**, 98-111.

Reenberg, A., T. Birch-Thomsen, O. Mertz, B. Fog, and S. Christiansen, 2008: Adaptation of human coping strategies in a small island society in the SW Pacific – 50 years of change in the coupled human-environment system on Bellona, Solomon Islands. *Human Ecology*, **36(6)**, 807-819.

Restrepo, J.C., L. Otero, A.C. Casas, A. Henao, and J. Gutiérrez, 2012: Shoreline changes between 1954 and 2007 in the marine protected area of the Rosario Island Archipelago (Caribbean of Colombia). *Ocean & Coastal Management*, **69**, 133-142.

Richmond, N. and B.K. Sovacool, 2012: Bolstering resilience in the coconut kingdom: improving adaptive capacity to climate change in Vanuatu. *Energy Policy*, **50**, 843-848.

Riedy, C. and I. McGregor, 2011: Climate governance is failing us: we all need to respond. *PORTAL Journal of Multidisciplinary International Studies*, **8(3 SI)**, http://epress.lib.uts.edu.au/journals/index.php/portal/issue/view/171.

Rocha, S., I. Ineich, and J. Harris, 2009: Cryptic variation and recent bipolar range expansion within the Stumped-Toed Gecko *Gehyra mutilata* across Indian and Pacific Ocean islands. *Contributions to Zoology*, **78(1)**, 1-8.

Rogers, T., K. Chmutina, and L.L. Moseley, 2012: The potential of PV installations in SIDS – an example in the island of Barbados. *Management of Environmental Quality: An International Journal*, **23(3)**, 284-290.

Romine, B.M. and C.H. Fletcher, 2013: A summary of historical shoreline changes on beaches of Kauai, Oahu, and Maui, Hawaii. *Journal of Coastal Research*, **29(3)**, 605-614.

Rongo, T. and R. van Woesik, 2011: Ciguatera poisoning in Rarotonga, southern Cook Islands. *Harmful Algae*, **10(4)**, 345-355.

Rosenberg, E., A. Kushmaro, E. Kramarsky-Winter, E. Banin, and L. Yossi, 2009: The role of microorganisms in coral bleaching. *The International Society for Microbial Ecology (ISME) Journal*, **3(2)**, 139-146.

Ross, M.S., J.J. O'Brien, R.G. Ford, K. Zhang, and A. Morkill, 2009: Disturbance and the rising tide: the challenge of biodiversity management on low-island ecosystems. *Frontiers in Ecology and the Environment*, **7(9)**, 471-478.

Rozell, D.J. and T.F. Wong, 2010: Effects of climate change on groundwater resources at Shelter Island, New York State, USA. *Hydrogeology Journal*, **18(7)**, 1657-1665.

Rudiak-Gould, P., 2012: Promiscuous corroboration and climate change translation: a case study from the Marshall Islands. *Global Environmental Change*, **22(1)**, 46-54.

Russell, L., 2009: *Poverty, Climate Change and Health in Pacific Island Countries.* Menzies Centre for Health Policy, University of Sydney, Sydney, NSW, Australia, 55 pp.

Santese, M., M.R. Perrone, A.S. Zakey, F. De Tomasi, and F. Giorgi, 2010: Modeling of Saharan dust outbreaks over the Mediterranean by RegCM3: case studies. *Atmospheric Chemistry and Physics*, **10(1)**, 133-156.

Sax, D.F. and S.D. Gaines, 2008: Species invasions and extinction: the future of native biodiversity on islands. *Proceedings of the National Academy of Sciences of the United States of America*, **105(1 Suppl.)**, 11490-11497.

Scheffers, A. and S. Scheffers, 2006: Documentation of the impact of Hurricane Ivan on the coastline of Bonaire (Netherlands Antilles). *Journal of Coastal Research*, **22(6)**, 1437-1450.

Schipper, L. and M. Pelling, 2006: Disaster risk, climate change and international development: scope for, and challenges to, integration. *Disasters*, **30(1 SI)**, 19-38.

Schleupner, C., 2008: Evaluation of coastal squeeze and its consequences for the Caribbean island Martinique. *Ocean & Coastal Management*, **51(5)**, 383-390.

Schofield, P.J., 2010: Update on geographic spread of invasive lionfishes (*Pterois volitans* [Linnaeus, 1758] and *P. miles* [Bennett, 1828]) in the western North Atlantic Ocean, Caribbean Sea and Gulf of Mexico. *Aquatic Invasions*, **5(1 Suppl.)**, S117-S122.

Schwarz, A., C. Béné, G. Bennett, D. Boso, Z. Hilly, C. Paul, R. Posala, S. Sibiti, and N. Andrew, 2011: Vulnerability and resilience of remote rural communities to shocks and global changes: empirical analysis from Solomon Islands. *Global Environmental Change*, **21(3)**, 1128-1140.

Scott, D., S. Gössling, and C.M. Hall, 2012a: International tourism and climate change. *Wiley Interdisciplinary Reviews: Climate Change*, **3(3)**, 213-232.

Scott, D., S. Gössling, and C.M. Hall, 2012b: *Climate Change and Tourism: Impacts, Adaptation and Mitigation.* Routledge, Abingdon, UK and New York, NY, USA, 437 pp.

Scott, D., M.C. Simpson, and R. Sim, 2012c: The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise. *Journal of Sustainable Tourism*, **20(6)**, 883-898.

Şekercioglu, C.H., S.H. Schneider, J.P. Fay, and S.R. Loarie, 2008: Climate change, elevational range shifts, and bird extinctions. *Conservation Biology*, **22(1)**, 140-150.

Senapathi, D., M.A.C. Nicoll, C. Teplitsky, C.G. Jones, and K. Norris, 2011: Climate change and the risks associated with delayed breeding in a tropical wild bird population. *Proceedings of the Royal Society B*, **278(1722)**, 3184-3190.

Shen, S. and F. Gemenne, 2011: Contrasted views on environmental change and migration: the case of Tuvaluan migration to New Zealand. *International Migration*, **49(s1 Suppl.)**, e224-e242.

Sinane, K., G. David, G. Pennober, and R. Troadec, 2010: Fragilisation et modification des formations littorales meubles sur l'île d'Anjouan (Comores): quand l'érosion d'origine anthropique se conjugue au changement climatique. *VertigO*, *La Revue Électronique en Sciences de l'Environnement*, **10(3)** (in French), http://vertigo.revues.org/10528?lang=en.

Solomon, S.M. and D.L. Forbes, 1999: Coastal hazards and associated management issues on South Pacific Islands. *Ocean & Coastal Management*, **42(6)**, 523-554.

Sovacool, B.K., 2012: Expert views of climate change adaptation in the Maldives. *Climatic Change*, **114(2)**, 295-300.

Spennemann, D.H.R., 1996: Nontraditional settlement patterns and typhoon hazard on contemporary Majuro Atoll, Republic of Marshall Islands. *Environmental Management*, **20(3)**, 337-348.

Srinivasan, U.T., 2010: Economics of climate change: risk and responsibility by world region. *Climate Policy*, **10(3)**, 298-316.

Steinberger, J.K., J. van Niel, and D. Bourg, 2009: Profiting from negawatts: Reducing absolute consumption and emissions through a performance-based energy economy. *Energy Policy*, **37(1)**, 361-370.

Stephenson, T.S., A.A. Chen, and M.A. Taylor, 2008: Toward the development of prediction models for the primary Caribbean dry season. *Theoretical and Applied Climatology*, **92(1-2)**, 87-101.

Storey, D. and S. Hunter, 2010: Kiribati: an environmental 'perfect storm'. *Australian Geographer*, **41(2)**, 167-181.

Stuart, E.K., 2006: Energizing the island community: a review of policy standpoints for energy in small island states and territories. *Sustainable Development*, **14(2)**, 139-147.

Swart, R. and F. Raes, 2007: Making integration of adaptation and mitigation work: mainstreaming into sustainable development policies. *Climate Policy*, **7(4)**, 288-303.

Tabucanon, G.M. and B. Opeskin, 2011: The resettlement of Nauruans in Australia: an early case of failed environmental migration. *The Journal of Pacific History*, **46(3)**, 337-356.

Takasaki, Y., 2011: Do the commons help augment mutual insurance among the poor? *World Development*, **39(3)**, 429-438.

Tanzil, J.T.I., B.E. Brown, and A.W. Tudhope, 2009: Decline in skeletal growth of the coral *Porites lutea* from the Andaman Sea, South Thailand between 1984 and 2005. *Coral Reefs*, **28(2)**, 519-528.

Taylor, M.A., A. Centella, J. Charlery, I. Borrajero, A. Benzanilla, J. Campbell, R. Rivero, T.S. Stephenson, F. Whyte, and R. Watson, 2007: *Glimpses of the Future: A Briefing from the PRECIS Caribbean Climate Change Project.* Published by the Climate Studies Group, Mona, for the Caribbean Community Climate Change Centre (CCCCC), Belmopan, Belize, 24 pp.

https://doi.org/10.1017/CBO9781107415386.009 Published online by Cambridge University Press

Taylor, M.A., F.S. Whyte, T.S. Stephenson, and J.D. Campbell, 2013: Why dry? Investigating the future evolution of the Caribbean Low Level Jet to explain projected Caribbean drying. *International Journal of Climatology*, **33(3)**, 784-792.

Techera, E., 2008: Customary law and community based conservation of marine areas in Fiji. In: *Beyond the Global Village. Environmental Challenges Inspiring Global Citizenship* [Hillerbrand, R. and R. Karlsson (eds.)]. Proceedings of the 6th Global Conference on Environmental Justice and Global Citizenship 2007 held by Inter-Disciplinary Net at Mansfield College, Oxford, UK, 2-5 July 2007, eBook, Interdisciplinary Press, Oxford, UK, pp. 107-121.

Tegart, W.J.M., G.W. Sheldon, and D.C. Griffiths, 1990: Policymakers' summary. In: *Climate Change: The IPCC Impacts Assessment. Contribution of Working Group II to the First Assessment Report of the Intergovernmental Panel on Climate Change* [Tegart, W.J.M., G.W. Sheldon, and D.C. Griffiths (eds.)]. Australian Government Publishing Service, Canberra, ACT, Australia, pp. 1-5.

Teles, F.R., 2011: Update on dengue in Africa. *Dengue Bulletin*, **35**, 35-51.

Terry, J.P. and A.C. Falkland, 2010: Responses of atoll freshwater lenses to storm-surge overwash in the northern Cook Islands. *Hydrogeology Journal*, **18(3)**, 749-759.

Terry, J.P., S. Garimella, and R.A. Kostaschuk, 2002: Rates of floodplain accretion in a tropical island river system impacted by cyclones and large floods. *Geomorphology*, **42(3-4)**, 171-182.

Tester, P.A., R.L. Feldman, A.W. Nau, S.R. Kibler, and R. Wayne Litaker, 2010: Ciguatera fish poisoning and sea surface temperatures in the Caribbean Sea and the West Indies. *Toxicon*, **56(5)**, 698-710.

Thiengo, S.C., A. Maldonado, E.M. Mota, E.J.L. Torres, R. Caldeira, O.S. Carvalho, A.P.M. Oliveira, R.O. Simoes, M.A. Fernandez, and R.M. Lanfredi, 2010: The giant African snail *Achatina fulica* as natural intermediate host of *Angiostrongylus cantonensis* in Pernambuco, northeast Brazil. *Acta Tropica*, **115(3)**, 194-199.

Thomas, A. and R. Leichenko, 2011: Adaptation through insurance: lessons from the NFIP. *International Journal of Climate Change Strategies and Management*, **3(3)**, 250-263.

Thomas-Hope, E. and A. Jardine-Comrie, 2007: Valuation of environmental resources for tourism in small island developing states: implications for planning in Jamaica. *International Development Planning Review*, **29(1)**, 93-112.

Tkachenko, K.S., 2012: The northernmost coral frontier of the Maldives: the coral reefs of Ihavandippolu Atoll under long-term environmental change. *Marine Environmental Research*, **82**, 40-48.

Tompkins, E.L., M.C. Lemos, and E. Boyd, 2008: A less disastrous disaster: managing response to climate-driven hazards in the Cayman Islands and NE Brazil. *Global Environmental Change*, **18(4)**, 736-745.

Tompkins, E.L., L. Hurlston, and W. Poortinga, 2009: Foreignness as a constraint on learning: the impact of migrants on disaster resilience in small islands. *Environmental Hazards*, **8(4)**, 263-277.

Tompkins, E.L., W.N. Adger, E. Boyd, S. Nicholson-Cole, K. Weatherhead, and N. Arnell, 2010: Observed adaptation to climate change: UK evidence of transition to a well-adapting society. *Global Environmental Change*, **20(4)**, 627-635.

Tsyban, A., J.T. Everett, and J. Titus, 1990: World oceans and coastal zones. In: *Climate Change: The IPCC Impacts Assessment. Report prepared for Intergovernmental Panel on Climate Change by Working Group II* [Tegart, W.J. McG., G.W. Sheldon, and D.C. Griffiths (eds.)]. Australian Government Publishing Service, Canberra, ACT, Australia, pp. 6-1 to 6-28.

Uno, I., K. Eguchi, K. Yumimoto, T. Takemura, A. Shimizu, M. Uematsu, Z. Liu, Z. Wang, Y. Hara, and N. Sugimoto, 2009: Asian dust transported one full circuit around the globe. *Nature Geoscience*, **2**, 557-560.

UNWTO, 2012: *Challenges and Opportunities for Tourism Development in Small Island Developing States*. United Nations World Tourism Organization (UNWTO), Madrid, Spain, 122 pp.

Uyarra, M.C., I.M. Cote, J.A. Gill, R.R.T. Tinch, D. Viner, and A.R. Watkinson, 2005: Island-specific preferences of tourists for environmental features: implications of climate change for tourism-dependent states. *Environmental Conservation*, **32(1)**, 11-19.

van Aalst, M.K., T. Cannon, and I. Burton, 2008: Community level adaptation to climate change: the potential role of participatory community risk assessment. *Global Environmental Change*, **18(1)**, 165-179.

van Alphen, K., H.S. Kunz, and M.P. Hekkert, 2008: Policy measures to promote the widespread utilization of renewable energy technologies for electricity generation in the Maldives. *Renewable and Sustainable Energy Reviews*, **12(7)**, 1959-1973.

van der Werf, G.R., D.C. Morton, R.S. DeFries, J.G.J. Olivier, P.S. Kasibhatla, R.B. Jackson, G.J. Collatz, and J.T. Randerson, 2009: CO_2 emissions from forest loss. *Nature Geoscience*, **2**, 737-738.

van Hooidonk, R., J. Maynard, and S. Planes, 2013: Temporary refugia for coral reefs in a warming world. *Nature Climate Change*, **3**, 508-511.

Van Kleef, E., H. Bambrick, and S. Hales, 2010: The geographic distribution of dengue fever and the potential influence of global climate change. *TropIKA.Net*, http://journal.tropika.net/pdf/tropika/2010nahead/a01v2n1.pdf.

van Ledden, M., G. Vaughn, J. Lansen, F. Wiersma, and M. Amsterdam, 2009: Extreme wave event along the Guyana coastline in October 2005. *Continental Shelf Research*, **29(1)**, 352-361.

Van Nostrand, J.M. and J.G. Nevius, 2011: Parametric insurance: using objective measures to address the impacts of natural disasters and climate change. *Environmental Claims Journal*, **23(3-4)**, 227-237.

Vassie, J.M., P.L. Woodworth, and M.W. Holt, 2004: An example of North Atlantic deep-ocean swell impacting ascension and St. Helena Islands in the central South Atlantic. *Journal of Atmospheric and Oceanic Technology*, **21(7)**, 1095-1103.

Voccia, A., 2012: Climate change: what future for small, vulnerable states? *International Journal of Sustainable Development & World Ecology*, **19(2)**, 101-115.

Walsh, K.J.E., K.L. McInnes, and J.L. McBride, 2012: Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific – a regional assessment. *Global and Planetary Change*, **80-81**, 149-164.

Warrick, O., 2009: Ethics and methods in research for community-based adaptation: reflections from rural Vanuatu. *Participatory Learning and Action*, **60**, 76-87.

Waycott, M., C.M. Duarte, T.J.B. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik, A. Calladine, J.W. Fourqurean, K.L. Heck, A.R. Hughes, G.A. Kendrick, W.J. Kenworthy, F.T. Short, and S.L. Williams, 2009: Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, **106(30)**, 12377-12381.

Waycott, M., L.J. McKenzie, J.E. Mellors, J.C. Ellison, M.T. Sheaves, C. Collier, A.M. Schwarz, A. Webb, J.E. Johnson, and C.E. Payri, 2011: Vulnerability of mangroves, seagrasses and intertidal flats in the tropical Pacific to climate change. In: *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change* [Bell, D., J.E. Johnson, and J.A. Hobday (eds.)]. Secretariat of the Pacific Community, Noumea, New Caledonia, pp. 297-368.

Webb, A.P., and P.S. Kench, 2010: The dynamic response of reef islands to sea-level rise: evidence from multi-decadal analysis of island change in the central Pacific. *Global and Planetary Change*, **72(3)**, 234-246.

Webb, N.R., S.J. Coulson, I.D. Hodkinson, W. Block, J.S. Bale, and A.T. Strathdee, 1998: The effects of experimental temperature elevation on populations of cryptostigmatic mites in high Arctic soils. *Pedobiologia*, **42(4)**, 298-308.

Weil, E. and A. Cróquer, 2009: Spatial variability in distribution and prevalence of Caribbean scleractinian coral and octocoral diseases. I. Community-level analysis. *Diseases of Aquatic Organisms*, **83(3)**, 195-208.

Weil, E. and C.S. Rogers, 2011: Coral reef diseases in the Atlantic-Caribbean. In: *Coral Reefs: An Ecosystem in Transition* [Dubinsky, Z. and N. Stambler (eds.)]. Springer, Dordrecht, Netherlands, pp. 465-491.

Weir, T. and Z. Virani, 2011: Three linked risks for development in the Pacific Islands: climate change, disasters and conflict. *Climate and Development*, **3(3)**, 193-208.

Westphal, M., M. Browne, K. MacKinnon, and I. Noble, 2008: The link between international trade and the global distribution of invasive alien species. *Biological Invasions*, **10(4)**, 391-398.

Wetzel, F.T., H. Beissmann, D.J. Penn, and W. Jetz, 2013: Vulnerability of terrestrial island vertebrates to projected sea-level rise. *Global Change Biology*, **19(7)**, 2058-2070.

Wheeler, D., 2011: *Quantifying Vulnerability to Climate Change: Implications for Adaptation Assistance.* CGD Working Paper 240, Center for Global Development (CGD), Washington, DC, USA, 49 pp.

White, I. and T. Falkland, 2010: Management of freshwater lenses in small Pacific islands. *Hydrogeology Journal*, **18(1)**, 227-246.

White, I., T. Falkland, P. Perez, A. Dray, T. Metutera, E. Metai, and M. Overmars, 2007: Challenges in freshwater management in low coral atolls. *Journal of Cleaner Production*, **15(16)**, 1522-1528.

Whyte, F.S., M.A. Taylor, T.S. Stephenson, and J.D. Campbell, 2008: Features of the Caribbean Low Level Jet. *International Journal of Climatology*, **28(1)**, 119-128.

Williams, G.J., I.S. Knapp, J.E. Maragos, and S.K. Davy, 2010: Modelling patterns of coral bleaching at a remote Pacific atoll. *Marine Pollution Bulletin*, **60(9)**, 1467-1476.

Willis, J.K. and J.A. Church, 2012: Regional sea-level projection. *Science*, **336(6081)**, 550-551.
Winters, L.A. and P.M. Martins, 2004: When comparative advantage is not enough: business costs in small remote economies. *World Trade Review*, **3(3)**, 347-383.
Woodroffe, C.D., 2008: Reef-island topography and the vulnerability of atolls to sea-level rise. *Global and Planetary Change*, **62(1-2)**, 77-96.
Yamamoto, L. and M. Esteban, 2010: Vanishing island states and sovereignty. *Ocean & Coastal Management*, **53(1)**, 1-9.
Yamano, H., H. Kayanne, T. Yamaguchi, Y. Kuwahara, H. Yokoki, H. Shimazaki, and M. Chicamori, 2007: Atoll island vulnerability to flooding and inundation revealed by historical reconstruction: Fongafale Islet, Funafuti Atoll, Tuvalu. *Global and Planetary Change*, **57(3-4)**, 407-416.
Yates, M.L., G. Le Cozannet, M. Garcin, E. Salaï, and P. Walker, 2013: Multidecadal atoll shoreline change on Manihi and Manuae, French Polynesia. *Journal of Coastal Research*, **29(4)**, 870-882.
Zahibo, N., E. Pelinovsky, T. Talipova, A. Rabinovich, A. Kurkin, and I. Nikolkina, 2007: Statistical analysis of cyclone hazard for Guadeloupe, Lesser Antilles. *Atmospheric Research*, **84(1)**, 13-29.

Annex 540

M. Burke et al., "Global non-linear effect of temperature on economic production", *Nature,* 2015

doi:10.1038/nature15725

Global non-linear effect of temperature on economic production

Marshall Burke[1,2]*, Solomon M. Hsiang[3,4]* & Edward Miguel[4,5]

Growing evidence demonstrates that climatic conditions can have a profound impact on the functioning of modern human societies[1,2], but effects on economic activity appear inconsistent. Fundamental productive elements of modern economies, such as workers and crops, exhibit highly non-linear responses to local temperature even in wealthy countries[3,4]. In contrast, aggregate macroeconomic productivity of entire wealthy countries is reported not to respond to temperature[5], while poor countries respond only linearly[5,6]. Resolving this conflict between micro and macro observations is critical to understanding the role of wealth in coupled human–natural systems[7,8] and to anticipating the global impact of climate change[9,10]. Here we unify these seemingly contradictory results by accounting for non-linearity at the macro scale. We show that overall economic productivity is non-linear in temperature for all countries, with productivity peaking at an annual average temperature of 13 °C and declining strongly at higher temperatures. The relationship is globally generalizable, unchanged since 1960, and apparent for agricultural and non-agricultural activity in both rich and poor countries. These results provide the first evidence that economic activity in all regions is coupled to the global climate and establish a new empirical foundation for modelling economic loss in response to climate change[11,12], with important implications. If future adaptation mimics past adaptation, unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100 and widening global income inequality, relative to scenarios without climate change. In contrast to prior estimates, expected global losses are approximately linear in global mean temperature, with median losses many times larger than leading models indicate.

Economic productivity—the efficiency with which societies transform labour, capital, energy, and other natural resources into new goods or services—is a key outcome in any society because it has a direct impact on individual wellbeing. While it is well known that temperature affects the dynamics of virtually all chemical, biological and ecological processes, how temperature effects recombine and aggregate within complex human societies to affect overall economic productivity remains poorly understood. Characterizing this influence remains a fundamental problem both in the emerging field of coupled human–natural systems and in economics more broadly, as it has implications for our understanding of historical patterns of human development and for how the future economy might respond to a changing climate.

Prior analyses have identified how specific components of economic production, such as crop yields, respond to temperature using high-frequency micro-level data[3,4]. Meanwhile, macro-level analyses have documented strong correlations between total economic output and temperature over time[5,6] and across space[13,14], but it is unknown whether these results are connected, and if so, how. In particular, strong responses of output to temperature observed in micro data from wealthy countries are not apparent in existing macro studies[5]. If wealthy populations actually are unaffected by temperature, this could indicate that wealth and human-made capital are substitutes for natural capital (for example, the composition of the atmosphere) in economic activity[5,7]. Resolving this apparent discrepancy thus has central implications for understanding the nature of sustainable development[7].

Numerous basic productive components of an economy display a highly non-linear relationship with daily or hourly temperature[1]. For example, labour supply[4], labour productivity[6], and crop yields[3] all decline abruptly beyond temperature thresholds located between 20 °C and 30 °C (Fig. 1a–c). However, it is unclear how these abrupt

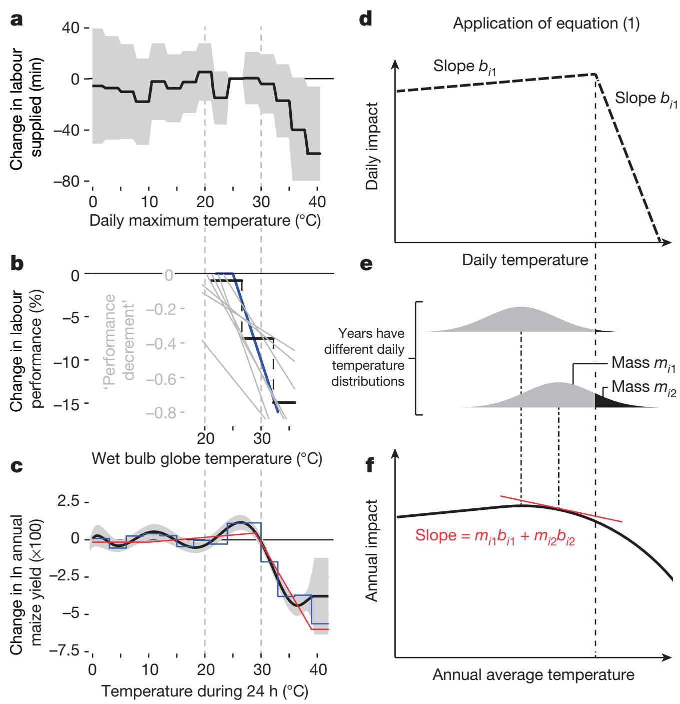


Figure 1 | Highly non-linear micro responses generate smooth and shifted macro response. **a–c**, Highly non-linear micro-level responses of labour supply[4] (**a**), labour performance[6] (**b**) and crop yield[3] (**c**) to daily temperature exposure exhibit similar 'kinked' structures between 20 and 30 °C. **d**, **e**, These micro-level responses ($f_i(T)$ in equation (1); **d**) map onto country-level distributions of temperatures across different locations and times within that country ($g_i(T-\overline{T})$ in equation (1); **e**). Shifts in country-level distributions correspond to changes in average annual temperature, altering the fraction of unit-hours (m_{i1} and m_{i2}) exposed to different regions of the micro-level response in **d**. **f**, Aggregating daily impacts according to equation (1) maps annual average temperature to annual output as a non-linear and concave function that is smoother than the micro response with a lower optimum ($Y(\overline{T})$ in equation (1)).

[1]Department of Earth System Science, Stanford University, California 94305, USA. [2]Center on Food Security and the Environment, Stanford University, California 94305, USA. [3]Goldman School of Public Policy, University of California, Berkeley, California 94720, USA. [4]National Bureau of Economic Research. [5]Department of Economics, University of California, Berkeley, California, 94720, USA.
*These authors contributed equally to this work.

declines at the micro level are reflected in coarser macro-level data. When production is integrated over large regions (for example, countries) or long units of time (for example, years), there is a broad distribution of momentary temperatures to which individual components of the economy (for example, crops or workers) are exposed. If only the hottest locations or moments cause abrupt declines in output, then when combined with many cooler and highly productive moments they would sum to an aggregate level of output that only declines modestly when aggregate average temperature increases.

To fix ideas, let function $f_i(T)$ describe the productive contribution of an individual productive unit in industry i (for example, a firm) relative to instantaneous (for example, daily) temperature T (Fig. 1d). For a given country, period, and industry, denote the fraction of unit-hours spent below the critical temperature threshold as m_{i1} and the fraction above as m_{i2} (Fig. 1e). The full distribution of unit-hours across all temperatures is $g_i(T-\overline{T})$, centred at average temperature $\overline{T}$. Assume $g_i(.)$ is mean zero. If productivity loss within a single productive unit-hour has limited impact on other units, as suggested by earlier findings[8,15], then aggregate production Y is the sum of output across industries, each integrated over all productive unit-hours in the country and period:

$$Y(\overline{T}) = \sum_i Y_i(\overline{T}) = \sum_i \int_{-\infty}^{\infty} f_i(T)\cdot g_i(T-\overline{T})dT \qquad (1)$$

As $\overline{T}$ rises and a country warms on average, m_{i2} increases gradually for all productive units (Fig. 1e). This growing number of hours beyond the temperature threshold imposes gradual but increasing losses on total output $Y(\overline{T})$.

Equation (1) predicts that $Y(\overline{T})$ is a smooth concave function (Fig. 1f) with a derivative that is the average derivative of $f_i(T)$ weighted by the number of unit-hours in each industry at each daily temperature. It also predicts that $Y(\overline{T})$ peaks at a temperature lower than the threshold value in $f_i(T)$, if the slope of $f_i(T)$ above the threshold is steeper than minus the slope below the threshold, as suggested by micro-scale evidence. These predictions differ fundamentally from notions that macro responses should closely mirror highly non-linear micro responses[6,16]. Importantly, while aggregate productivity losses ought to occur contemporaneous with temperature changes, these changes might also influence the long-run trajectory of an economy's output[5,15]. This could occur, for example, if temporary contemporaneous losses alter the rate of investment in new productive units, thereby altering future production. See Supplementary Equations 1–14 for details.

We test these predictions using data on economic production[17] for 166 countries over the period 1960–2010. In an ideal experiment, we would compare two identical countries, warm the temperature of one and compare its economic output to the other. In practice, we can approximate this experiment by comparing a country to itself in years when it is exposed to warmer- versus cooler-than-average temperatures[18] due to naturally occurring stochastic atmospheric changes. Heuristically, an economy observed during a cool year is the 'control' for that same society observed during a warmer 'treatment' year. We do not compare output across different countries because such comparisons are probably confounded, distinguishing our approach from cross-sectional studies that attribute differences across countries to their temperatures[13].

We estimate how economic production changes relative to the previous year—that is, annual economic growth—to purge the data of secular factors in each economy that evolve gradually[5]. We deconvolve economic growth to account for: (1) all constant differences between countries, for example, culture or history; (2) all common contemporaneous shocks, for example, global price changes or technological innovations; (3) country-specific quadratic trends in growth rates, which may arise, for example, from changing political institutions or economic policies; and (4) the possibly non-linear effects of annual average temperature and rainfall. This approach is more reliable than only adjusting for observed variables because it accounts for unobserved time-invariant and time-trending covariates, allows these covariates to influence different countries in different ways, and outperforms alternative models along numerous dimensions[15] (see Supplementary Information). In essence, we analyse whether country-specific deviations from growth trends are non-linearly related to country-specific deviations from temperature and precipitation trends, after accounting for any shocks common to all countries.

We find country-level economic production is smooth, non-linear, and concave in temperature (Fig. 2a), with a maximum at 13 °C, well below the threshold values recovered in micro-level analyses and consistent with predictions from equation (1). Cold-country productivity increases as annual temperature increases, until the optimum. Productivity declines gradually with further warming, and this decline accelerates at higher temperatures (Extended Data Fig. 1a–g). This

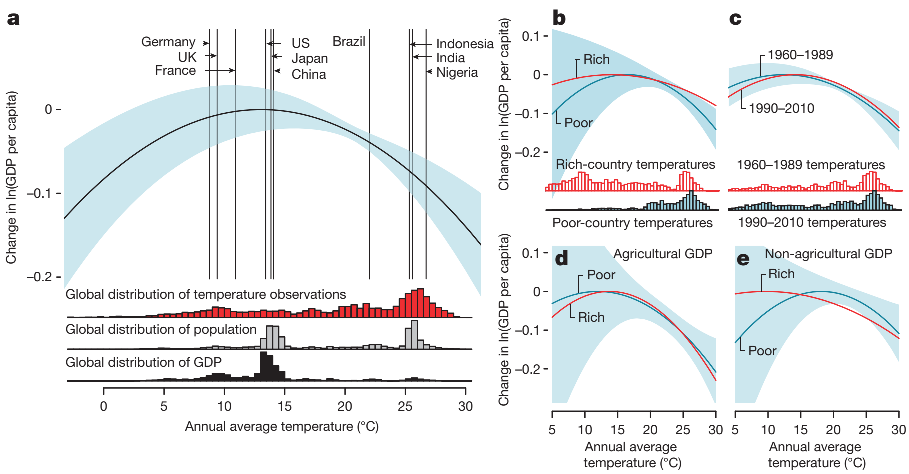


Figure 2 | Effect of annual average temperature on economic production. **a**, Global non-linear relationship between annual average temperature and change in log gross domestic product (GDP) per capita (thick black line, relative to optimum) during 1960–2010 with 90% confidence interval (blue, clustered by country, $N = 6{,}584$). Model includes country fixed effects, flexible trends, and precipitation controls (see Supplementary Methods). Vertical lines indicate average temperature for selected countries, although averages are not used in estimation. Histograms show global distribution of temperature exposure (red), population (grey), and income (black). **b**, Comparing rich (above median, red) and poor (below median, blue) countries. Blue shaded region is 90% confidence interval for poor countries. Histograms show distribution of country–year observations. **c**, Same as **b** but for early (1960–1989) and late (1990–2010) subsamples (all countries). **d**, Same as **b** but for agricultural income. **e**, Same as **b** but for non-agricultural income.

result is globally representative and not driven by outliers (Extended Data Fig. 1h). It is robust to estimation procedures that allow the response of countries to change as they become richer (Extended Data Fig. 1i and Supplementary Table 1), use higher-order polynomials or restricted cubic splines to model temperature effects (Extended Data Fig. 1j–k), exclude countries with few observations, exclude major oil producers, exclude China and the United States, account for continent-specific annual economic shocks[19], weaken assumptions about trends in growth, account for multiple lags of growth, and use alternative economic data sources[20] (Extended Data Table 1).

Accounting for delayed effects of temperature, which might be important if countries 'catch up' after temporary losses, increases statistical uncertainty but does not alter the net negative average effect of hot temperatures (Extended Data Fig. 2a–c). This 'no catch up' behaviour is consistent with the observed response to other climatological disturbances, such as tropical cyclones[15].

While much of global economic production is clustered near the estimated temperature optimum (Fig. 2a, black histogram), both rich and poor countries exhibit similar non-linear responses to temperature (Fig. 2b). Poor tropical countries exhibit larger responses mainly because they are hotter on average, not because they are poorer (Extended Data Fig. 1i and Supplementary Table 1). There is suggestive evidence that rich countries might be somewhat less affected by temperature, as previously hypothesized[5], but their response is statistically indistinguishable from poor countries at all temperatures (Extended Data Fig. 2d–f and Extended Data Table 2). Although the estimated total effect of high temperatures on rich countries is substantially less certain because there are few hot, rich countries in the sample, the non-linearity of the rich-country response alone is statistically significant ($P < 0.1$; Extended Data Table 2), and we estimate an 80% likelihood that the marginal effect of warming is negative at high temperatures in these countries (Extended Data Fig. 2m). Our finding that rich countries respond non-linearly to temperature is consistent with recent county-level results in the United States[8].

Our non-linear results are also consistent with the prior finding of no linear correlation between temperature and growth in rich countries[5]. Because the distribution of rich-country temperatures is roughly symmetrical about the optimum, linear regression recovers no association. Accounting for non-linearity reconciles this earlier result (Extended Data Fig. 3a and Supplementary Table 3) but reverses how wealth and technology are understood to mediate economic responses to temperature.

We do not find that technological advances or the accumulation of wealth and experience since 1960 has fundamentally altered the relationship between productivity and temperature. Results using data from 1960–1989 and 1990–2010 are nearly identical (Fig. 2c). In agreement with recent micro-level evidence[8,21], substantial observed warming over the period apparently did not induce notable adaptation.

Consistent with micro-level findings that both agricultural and non-agricultural labour-related productivity are highly non-linear in instantaneous temperature[3,4,6], we find agricultural and non-agricultural aggregate production are non-linear in average annual temperature for both rich and poor countries (Fig. 2d, e and Extended Data Fig. 2g–l). Low temperature has no significant effect on these subsamples, although limited poor-country exposure to these temperatures severely limits statistical precision. High temperatures have significant negative effects in all cases for poor countries, and significant or marginally significant effects for rich countries (Extended Data Fig. 2p–u).

A global non-linear response of economic production to annual temperature has important implications for the likely economic impact of climate change. We find only weak suggestive evidence that richer populations are less vulnerable to warming, and no evidence that experience with high temperatures or technological advances since 1960 have altered the global response to temperature. This suggests that adaptation to climatic change may be more difficult than previously believed[9,10], and that the accumulation of wealth, technology and experience might not substantially mitigate global economic losses during this century[8,21].

We quantify the potential impact of warming on national and global incomes by combining our estimated non-linear response function with 'business as usual' scenarios (Representative Concentration Pathway (RCP)8.5) of future warming and different assumptions regarding future baseline economic and population growth[22] (see Supplementary Information). This approach assumes future economies respond to temperature changes similarly to today's economies—perhaps a reasonable assumption given the observed lack of adaptation during our 50-year sample.

In 2100, we estimate that unmitigated climate change will make 77% of countries poorer in per capita terms than they would be without climate change. Climate change may make some countries poorer in the future than they are today, depending on what secular growth rates are assumed. With high baseline growth and unmitigated climate change (RCP8.5 and Shared Socio-economic Pathway (SSP)5; see Supplementary Information), we project that 5% of countries are poorer in 2100 than today (Fig. 3a), while with low growth, 43% are (SSP3; Fig. 3b).

Differences in the projected impact of warming are mainly a function of countries' baseline temperatures, since warming raises productivity in cool countries (Fig. 4). In particular, Europe could benefit from increased average temperatures. Because warming harms productivity in countries with high average temperatures, incomes in poor regions are projected to fall relative to a world without climate change with high confidence ($P < 0.01$), regardless of the statistical approach used. Models allowing for delayed effects project more negative impacts in colder wealthy regions; projections assuming rich and poor countries respond differently (Fig. 2b) are more uncertain because fewer data are used to estimate each response (Extended Data Fig. 4).

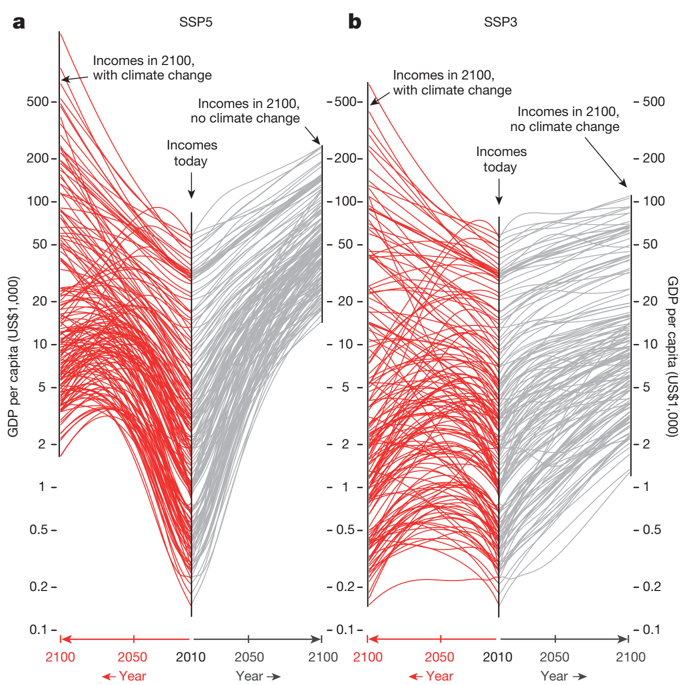


Figure 3 | Country-level income projections with and without temperature effects of climate change. **a**, **b**, Projections to 2100 for two socioeconomic scenarios[22] consistent with RCP8.5 'business as usual' climate change: **a**, SSP5 assumes high baseline growth and fast income convergence; **b**, SSP3 assumes low baseline growth and slow convergence. Centre in each panel is 2010, each line is a projection of national income. Right (grey) are incomes under baseline SSP assumptions, left (red) are incomes accounting for non-linear effects of projected warming.

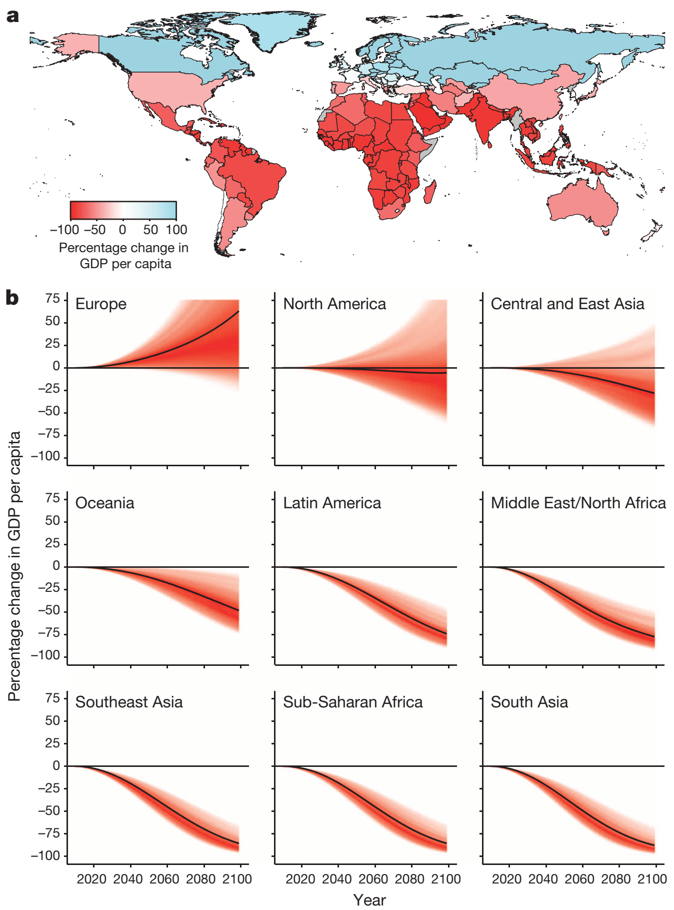


Figure 4 | Projected effect of temperature changes on regional economies. **a**, **b**, Change in GDP per capita (RCP8.5, SSP5) relative to projection using constant 1980–2010 average temperatures. **a**, Country-level estimates in 2100. **b**, Effects over time for nine regions. Black lines are projections using point estimates. Red shaded area is 95% confidence interval, colour saturation indicates estimated likelihood an income trajectory passes through a value[27]. Base maps by ESRI.

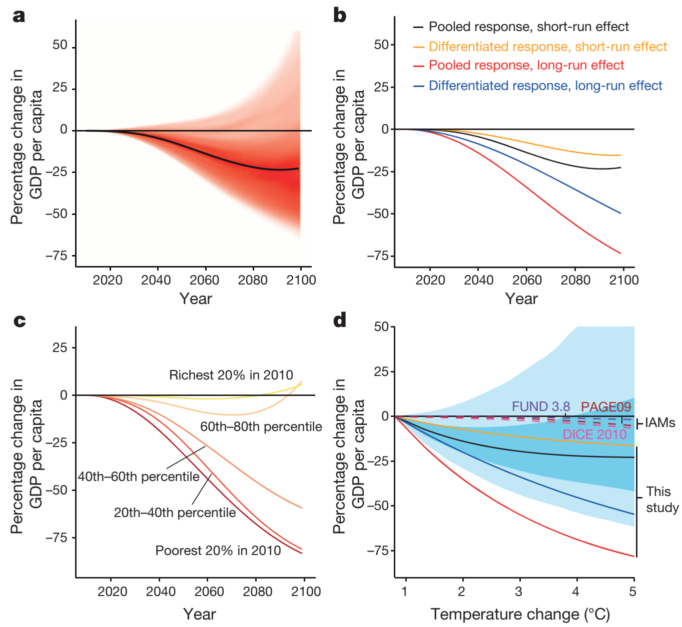


Figure 5 | Global damage estimates arising from non-linear effects of temperature. **a**, Change in global GDP by 2100 using benchmark model (Fig. 2a). Calculation and display are the same as Fig. 4. **b**, Same as **a** (point estimate only) comparing approaches to estimating temperature effects (pooled/differentiated: rich and poor countries assumed to respond identically/differently, respectively; short run/long run: effects account for 1 or 5 years of temperature, respectively; see Supplementary Methods). **c**, Mean impacts by 2010 income quintile (benchmark model). **d**, Projected income loss in 2100 (SSP5) for different levels of global mean temperature increase, relative to pre-industrial temperatures. Solid lines marked as in **b**. Blue shaded areas are interquartile range and 5th–95th percentile estimates. Dashed lines show corresponding damages from major integrated assessment models (IAMs)[12].

The impact of warming on global economic production is a population-weighted average of country-level impacts in Fig. 4a. Using our benchmark model (Fig. 2a), climate change reduces projected global output by 23% in 2100 (best estimate, SSP5) relative to a world without climate change, although statistical uncertainty allows for positive impacts with probability 0.29 (Fig. 5a and Extended Data Table 3). Estimates vary in magnitude, but not in structure, depending on the statistical approach (Fig. 5b and Extended Data Table 3). Models with delayed impacts project larger losses because cold countries gain less, while differentiated rich–poor models have smaller losses (statistical uncertainty allows positive outcomes with probability 0.09–0.40). Models allowing both delayed impacts and differentiated rich–poor responses (the most flexible approach) project global losses 2.2 times larger than our benchmark approach. In all cases, the likelihood of large global losses is substantial: global losses exceed 20% of income with probability 0.44–0.87 (Extended Data Table 3 and Extended Data Fig. 5).

Accounting for the global non-linear effect of temperature is crucial to constructing income projections under climate change because countries are expected to become both warmer and richer in the future. In a previous analysis in which a linear relationship was assumed and no significant linear effect was observed in rich countries[5], it was hypothesized that countries adapted effectively to temperature as they became wealthier. Under this hypothesis, the impacts of future warming should lessen over time as countries become richer. In contrast, when we account for the non-linear effect of temperature historically, we find that rich and poor countries behave similarly at similar temperatures, offering little evidence of adaptation. This indicates that we cannot assume rich countries will be unaffected by future warming, nor can we assume that the impacts of future warming will attenuate over time as countries become wealthier. Rather, the impact of additional warming worsens over time as countries becomes warmer. As a result, projections using linear and non-linear approaches diverge substantially—by roughly 50–200% in 2100 (Extended Data Fig. 3c, d)—highlighting the importance of accounting for this non-linearity when assessing the impacts of future warming.

Strong negative correlation between baseline income and baseline temperature indicates that warming may amplify global inequality because hot, poor countries will probably suffer the largest reduction in growth (Fig. 5c). In our benchmark estimate, average income in the poorest 40% of countries declines 75% by 2100 relative to a world without climate change, while the richest 20% experience slight gains, since they are generally cooler. Models with delayed impacts do not project as dramatic differences because colder countries also suffer large losses (Extended Data Fig. 5).

We use our results to construct an empirical 'damage function' that maps global temperature change to global economic loss by aggregating country-level projections. Damage functions are widely used in economic models of global warming, but previously relied on theory for structure and rough estimates for calibration[11,12]. Using our empirical results, we project changes to global output in 2100 for different temperature changes (Fig. 5d; see Supplementary Information) and compare these to previously estimated damage functions[12]. Commonly used functions are within our estimated uncertainty, but differ in two important respects.

First, our projected global losses are roughly linear—and slightly concave—in temperature, not quadratic or exponential as previously theorized. Approximate linearity results from the broad distribution of temperature exposure within and across countries, which causes the country-weighted average derivative of the productivity function in Fig. 2a to change little as countries warm and prevents abrupt transitions in global output even though the contribution of individual productive units are highly non-linear (see Fig. 1). Global losses are slightly concave in global temperature because the effect of compounding negative growth declines mechanically over time (Extended Data Fig. 6e and Supplementary Information). These properties are independent of the growth scenario and response function (Extended Data Fig. 6a).

Second, the slope of the damage function is large even for slight warming, generating expected costs of climate change 2.5–100 times larger than prior estimates for 2 °C warming, and at least 2.5 times larger for higher temperatures (Extended Data Fig. 6b–d). Notably, our estimates are based only on temperature effects (or effects for which historical temperature has been a proxy), and so do not include other potential sources of economic loss associated with climate change, such as tropical cyclones[15] or sea-level rise[23], included in previous damage estimates.

If societies continue to function as they have in the recent past, climate change is expected to reshape the global economy by substantially reducing global economic output and possibly amplifying existing global economic inequalities, relative to a world without climate change. Adaptations such as unprecedented innovation[24] or defensive investments[25] might reduce these effects, but social conflict[2] or disrupted trade[26]—either from political restrictions or correlated losses around the world—could exacerbate them.

Online Content Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

Received 3 April; accepted 15 September 2015.
Published online 21 October 2015.

1. Dell, M., Jones, B. F. & Olken, B. A. What do we learn from the weather? The new climate-economy literature. *J. Econ. Lit.* **52,** 740–798 (2014).
2. Hsiang, S. M., Burke, M. & Miguel, E. Quantifying the influence of climate on human conflict. *Science* **341,** 1235367 (2013).
3. Schlenker, W. & Roberts, M. J. Non-linear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proc. Natl Acad. Sci. USA* **106,** 15594–15598 (2009).
4. Graff Zivin, J. & Neidell, M. Temperature and the allocation of time: Implications for climate change. *J. Labor Econ.* **13,** 1–26 (2014).
5. Dell, M., Jones, B. F. & Olken, B. A. Climate change and economic growth: evidence from the last half century. *Am. Econ. J. Macroecon.* **4,** 66–95 (2012).
6. Hsiang, S. M. Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. *Proc. Natl Acad. Sci. USA* **107,** 15367–15372 (2010).
7. Solow, R. in *Economics of the Environment* (ed. Stavins, R.) (W. W. Norton & Company, 2012).
8. Deryugina, T. & Hsiang, S. M. Does the environment still matter? Daily temperature and income in the United States. *NBER Working Paper* 20750 (2014).
9. Tol, R. S. J. The economic effects of climate change. *J. Econ. Perspect.* **23,** 29–51 (2009).
10. Nordhaus, W. *A Question of Balance: Weighing the Options on Global Warming Policies* (Yale Univ. Press, 2008).
11. Pindyck, R. S. Climate change policy: what do the models tell us? *J. Econ. Lit.* **51,** 860–872 (2013).
12. Revesz, R. L. *et al.* Global warming: improve economic models of climate change. *Nature* **508,** 173–175 (2014).
13. Nordhaus, W. D. Geography and macroeconomics: new data and new findings. *Proc. Natl Acad. Sci. USA* **103,** 3510–3517 (2006).
14. Dell, M., Jones, B. F. & Olken, B. A. Temperature and income: reconciling new cross-sectional and panel estimates. *Am. Econ. Rev.* **99,** 198–204 (2009).
15. Hsiang, S. M. & Jina, A. The causal effect of environmental catastrophe on long run economic growth. *NBER Working Paper* 20352 (2014).
16. Heal, G. & Park, J. Feeling the heat: temperature, physiology & the wealth of nations. *NBER Working Paper* 19725 (2013).
17. World Bank Group. *World Development Indicators 2012* (World Bank Publications, 2012).
18. Matsuura, K. & Willmott, C. J. Terrestrial air temperature and precipitation: monthly and annual time series (1900–2010) v. 3.01. http://climate.geog.udel.edu/~climate/html_pages/README.ghcn_ts2.html (2012).
19. Hsiang, S. M., Meng, K. C. & Cane, M. A. Civil conflicts are associated with the global climate. *Nature* **476,** 438–441 (2011).
20. Summers, R. & Heston, A. The Penn World Table (Mark 5): an expanded set of international comparisons, 1950–1988. *Q. J. Econ.* **106,** 327–368 (1991).
21. Burke, M. & Emerick, K. Adaptation to climate change: evidence from US agriculture. *Am. Econ. J. Econ. Pol*. (in the press).
22. O'Neill, B. C. *et al.* A new scenario framework for climate change research: the concept of shared socioeconomic pathways. *Clim. Change* **122,** 387–400 (2014).
23. Houser, T. *et al. Economic Risks of Climate Change: An American Prospectus* (Columbia Univ. Press, 2015).
24. Olmstead, A. L. & Rhode, P. W. Adapting North American wheat production to climatic challenges, 1839–2009. *Proc. Natl Acad. Sci. USA* **108,** 480–485 (2011).
25. Barreca, A., Clay, K., Deschenes, O., Greenstone, M. & Shapiro, J. S. Adapting to climate change: the remarkable decline in the US temperature-mortality relationship over the 20th century. *J. Polit. Econ*. (in the press).
26. Costinot, A., Donaldson, D. & Smith, C. Evolving comparative advantage and the impact of climate change in agricultural markets: evidence from a 9 million-field partition of the earth. *J. Polit. Econ*. (in the press).
27. Hsiang, S. M. Visually-weighted regression. *SSRN Working Paper* 2265501 (2012).

Supplementary Information is available in the online version of the paper.

Acknowledgements We thank D. Anthoff, M. Auffhammer, V. Bosetti, M. P. Burke, T. Carleton, M. Dell, L. Goulder, S. Heft-Neal, B. Jones, R. Kopp, D. Lobell, F. Moore, J. Rising, M. Tavoni, and seminar participants at Berkeley, Harvard, Princeton, Stanford universities, Institute for the Study of Labor, and the World Bank for useful comments.

Author Contributions M.B. and S.M.H. conceived of and designed the study; M.B. and S.M.H. collected and analysed the data; M.B., S.M.H. and E.M. wrote the paper.

Author Information Replication data have been deposited at the Stanford Digital Repository (http://purl.stanford.edu/wb587wt4560). Reprints and permissions information is available at www.nature.com/reprints. The authors declare no competing financial interests. Readers are welcome to comment on the online version of the paper. Correspondence and requests for materials should be addressed to M.B. (mburke@stanford.edu).

Annex 541

C. Donovan & C. Corbishley, "The cost of capital and how it affects climate change mitigation investment", *Imperial College London Grantham Institute Briefing Paper No. 15*, 2016

Imperial College London

Grantham Institute
Briefing paper No 15

January 2016

The cost of capital and how it affects climate change mitigation investment

DR CHARLES DONOVAN AND CHRISTOPHER CORBISHLEY

Headlines

- The cost of capital, also known as the minimum required rate of return, is a crucial factor in investment decision-making in the private sector.
- Assumptions made by government policymakers about cost of capital in the private sector often turn out to be wrong. These errors arise because the cost of capital amongst firms is highly disparate and nearly impossible to estimate precisely.
- Cost of capital estimation errors have resulted in substantial economic welfare losses. Recent examples suggest that when governments take proper account of the cost of capital as an investment decision variable, outcomes for both the public and private sector are vastly improved.
- As the cost of capital for private sector investors is driven by risk perceptions, reducing investment risk is of paramount importance for governments seeking to minimize taxpayer support for new low-carbon infrastructure.

Introduction

Combatting climate change will require a transformation of investment patterns in the energy sector. Governmental efforts are being made amidst a difficult transition in energy markets during which private companies have progressively replaced state-owned enterprises as principal investors.

In the United Kingdom, for example, 25 years ago electricity was generated, distributed and sold exclusively by government entities. Today, government bodies no longer invest in the electricity supply chain, having been replaced by a host of shareholder-driven investors, including corporations, investment banks and private equity firms. With some notable exceptions, there has been a global shift in the role of government from investor to market regulator[1]. Nowhere is this change more evident than in clean and renewable energy, which is comprised, with few exceptions, of firms generating profits for shareholders.

Last year was a watershed moment in the renewable energy industry's short history. Total global investment in renewables came within striking distance of the amount invested in fossil-fuel power and the uptake of renewables in developing countries reached an all-time high. It was a particularly remarkable year for solar photovoltaic (PV) technology, as the cost of solar electricity generation became cheaper than the retail price of electricity in many regions around the world. It is hard to imagine how these accomplishments could have been made without the competitive forces and ingenuity of the private sector.

Contents

Grantham Briefing Papers analyse climate change and environmental research linked to work at Imperial, setting it in the context of national and international policy and the future research agenda. This paper and other Grantham publications are available from **www.imperial.ac.uk/grantham/publications**

Yet, the current system is far from perfect. In a myriad of ways, governments act to influence the price of energy to consumers and enhance welfare benefits to society at large. These interventions include not only subsidies, but also tax policies, accounting standards, and grant programs. As regulators, the recurring question for governments is how much support is needed. Framed in purely economic terms the question is one of efficiency; that is, 'what is the minimum level of incentive required to trigger investment by the private sector?' Unfortunately, recent history indicates that regulators are not equipped with sufficiently accurate models to answer this question.

Over the coming decades, governments will seek to influence trillions of dollars of annual investment decisions in order to mitigate the effects of climate change. In aggregate, the incremental investment required to limit warming to 2°C above pre-industrial levels has been estimated to be just shy of US$1 trillion per year[2]. That is a trillion dollars of investment that may or may not be made, based on decisions taken by a diverse investment community spread across financial capitals all over the world.

While many parameters of these investment decisions, are known to both firms and governments policymakers are often ill-informed about the most important decision input: the cost of capital. Despite its importance, the cost of capital is generally poorly understood by non-finance specialists. The objective of this paper is to shed light on this important issue by exploring how businesses estimate their cost of capital, a crucial determinant in investment choices.

This briefing note is divided into three sections. The first section presents an overview of cost of capital and the estimation methods used within shareholder-driven companies, highlighting important differences between theory and practice. Section two investigates how the cost of capital varies by technology and by country. Finally in section three, we describe how investment policies can be improved in light of these complexities.

Risk and return as measured by governments: The discount rate

Mitigation efforts on the scale required for climate stabilization will, by and large, depend upon investments made by the private sector, which makes investment decisions based on market-oriented rates of return. Yet public economic appraisals must also assess actions taken now against their possible consequences in future.

Box 1: Two climate change mitigation technologies explained

Solar PV

The defining characteristic of solar photovoltaic (PV) technology is the direct conversion of sunlight into electricity. Many technologies continue to vie for market supremacy including conventional crystalline silicon (c-Si), thin film, and concentrator photovoltaics. The continued decline in the cost of PV technology is set to drive a US$3.7 trillion surge in investment over the next 25 years[7]. Large utility-scale solar power plants have the potential to out-compete gas and coal in sunny and fossil-fuel constrained locations, while a revolution is already taking place on residential and commercial rooftops. Small-scale installations have already reached cost parity in many regions around the world, especially those where diesel generators are the norm. The spectacular growth in solar PV installations worldwide has resulted from both technological progress and financial innovation, such as solar PV leasing.

Carbon dioxide capture and storage (CCS) and carbon sequestration

CCS and carbon capture and sequestration can be used to reduce net greenhouse gas emissions. In the case of geological sequestration, carbon dioxide is captured at its source, such as from coal and gas fired power plants and large industrial processes, and subsequently stored in non-atmospheric reservoirs, for example depleted oil and gas reservoirs, deep saline formations and deep ocean water. Terrestrial sequestration, on the other hand, seeks to enhance natural or chemical processes to increase the removal of carbon from the atmosphere, through forestation, modification of agricultural practices, ocean and biomass-related technologies.

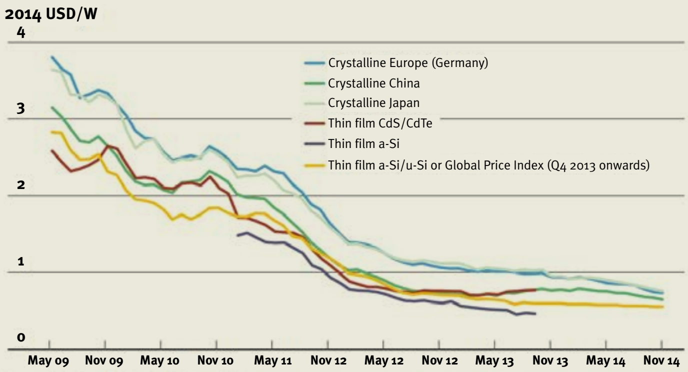


Figure 1: Average monthly solar PV module prices by technology and manufacturing country sold in Europe (2009 - 2014)[6]. Source: Irena, 2014

CCS has received growing interest, in part, due to its compatibility with the large energy production and delivery infrastructure already in place. The International Energy Agency (IEA) predicts that one-fifth of the carbon dioxide reductions necessary by 2050 will come from CCS. The challenge, however, is that large-scale CCS is still prohibitively expensive.

In the field of public policy, the discount rate is a crucial input to sound decision-making. Governments acting as investors in important public goods such as health and education must consider the cost and benefits of potential investments by conducting inter-temporal valuations. That is, as future costs and benefits to society typically span many decades, they must be made equivalent to costs and benefits today. Alongside cost-benefit analysis, the single parameter that captures the range of motives underlying inter-temporal choice is the discount rate[3].

Given the scale of costs and benefits and the time horizon involved, the perceived wisdom of climate change mitigation is highly dependent upon the discount rate employed. The Stern Review on Climate Change kicked-off an important debate about the discount rate for climate change mitigation investments, bringing a traditionally obscure topic under public scrutiny. The fundamental tension in this debate is whether the discount rate should be derived from a social rate of time preference[4] or observed from market rates[5].

Private sector investment decision-making

Firms look at a range of possible returns across multiple projects before deciding whether to proceed with an investment. These decisions are based on an assessment of the relative risk and return and how the new investment fits within their existing portfolio. Valuation methods differ according to the asset class being analysed as well as investor sophistication.

The most widely-used criteria for investment decision-making are the net present value (NPV) and internal rate of return (IRR) decision rules. They are often referred to separately but they are in fact variations on an identical premise: an investment project should be undertaken only when the project generates a total financial return greater than the cost of funding it.

In the NPV rule, total financial return is represented by the sum of all project cash flows, discounted by the cost of capital. Using the IRR rule, the cost of capital is compared directly to the annualised percentage gain on capital invested. The common denominator in both methods is the opportunity cost of capital ascribed to the project.

Many companies adopt a third valuation method known as the payback period (PBP), which divides the cost of the project by the annual cash flows to determine the number of years it takes to offset the initial capital outlay. The drawback of this technique is its failure to account for the opportunity cost of capital (the return rate achievable from a similar project or asset class).

Net present value (NPV)

$$NPV = -I_o + \frac{CF_1}{1+k} + \frac{CF_2}{(1+k)^2} + \ldots + \frac{CF_t}{(1+k)^t} = \sum_{t=o}^{n} \frac{CF_t}{(1+k)_t}$$

Where:

I_o = *Initial Investment*
CF = *Cash Flow*
k = *Discount Rate*
t = *Time*

Internal rate of return (IRR)

$$NPV = 0 = -I_o + \frac{CF_1}{1+IRR} + \frac{CF_2}{(1+IRR)^2} + \ldots + \frac{CF_t}{(1+IRR)^t} = \sum_{t=o}^{n} \frac{CF_1}{(1+IRR)_t}$$

Payback period (PBP)

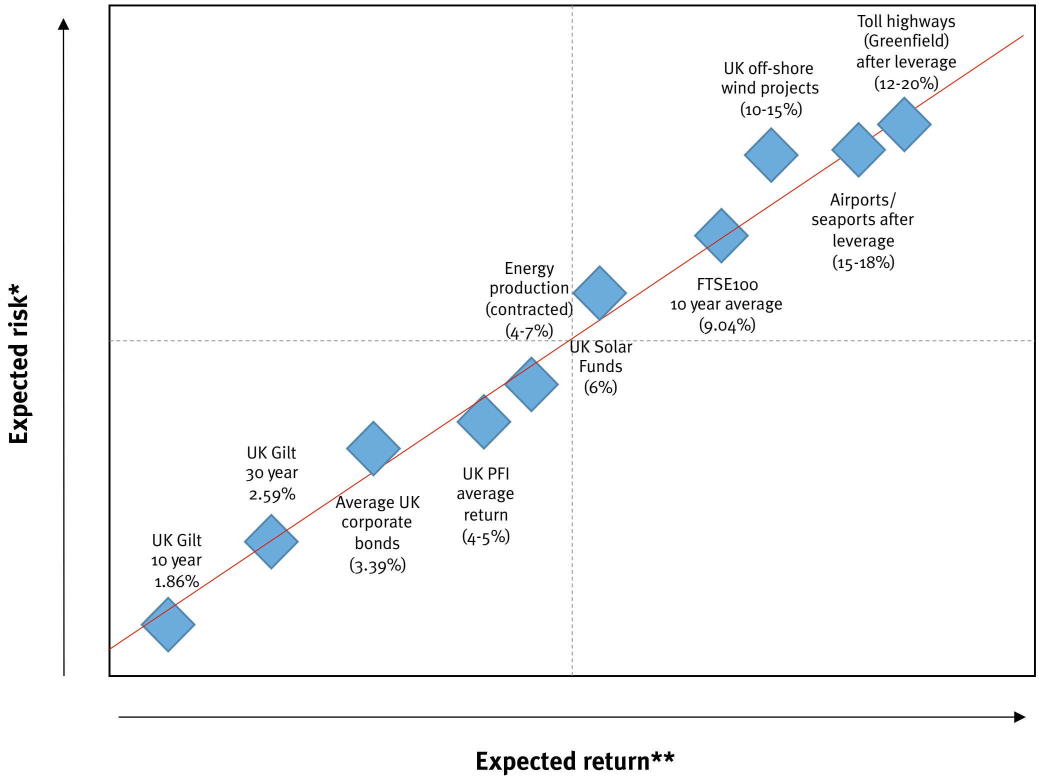
$$Payback\ Period = \frac{Total\ Investment}{Cash\ Inflow\ (Net\ Profit)}$$

Estimating the cost of capital

The basic and uncontroversial starting point for understanding the cost of capital is to recognize a positive relationship between risk and required financial return. Higher levels of risk lead to increases in the cost of capital. The stylized relationship between risk and the cost of capital and an indicative positioning of generic types of investments along this continuum is shown in Figure 2.

Financial return is expressed numerically as a percentage and there is little need for additional interpretation of its meaning. Risk, on the other hand, is not so easy. In fact, defining risk has been the lifelong obsession of numerous mathematicians, philosophers and economists and is a task that has consumed the attention of some of the world's greatest thinkers for more than a century[8].

Here, we take a practical approach to risk. A good way to understand the risk of investing in real assets, for example wind farms, is to consider the capital structure of a typical investment project. The capital structure describes the proportions of debt and equity that will be used as sources of funding for the project. Within a single investment project, equity financing will always be more expensive than debt financing. The reason for this difference is that providers of debt capital (lenders) have a primary claim on the assets of the company, while the providers of equity capital (shareholders) have a residual claim. The ranking of legal rights between shareholders and lenders is founded on the premise that the firm's shareholders possess greater knowledge and control over the business and should therefore bear greater risk. But to fully appreciate the higher level of risk faced by shareholders, one must consider what happens when things go wrong.



* Expected risk is defined by the risk scores assigned to assets by banks and rating agencies.
** Expected return is defined as average annual return. Source: Bloomberg, UKT&I, Hargreaves Lansdowne, JP Morgan.

Figure 2: Illustration of risk-return profiles among private investors in renewable energy.

Box 2: What's in a name?

Although the term 'cost of equity' is used frequently by both finance academics and practitioners, it is more accurately called the 'expected return on equity'. While it's a slight change of wording, the quibble is more than semantics. The rate of return on equity is fundamentally uncertain, due to the nature of financial gains to shareholders. Unlike a loan, the timing and amount of future payments to be received are uncertain and cannot be known in advance.

Ultimately, the rate of return anticipated by equity investors is a subjective set of expectations regarding the future; most importantly expectations about the future value of the venture. Furthermore, payments to shareholders are not tax-deductible, as are interest payments. It is, therefore, inaccurate and potentially misleading to describe the expected return on equity as a cost[9]. Nonetheless, it is now an accepted convention to use the 'cost of equity' interchangeably with 'expected return on equity'.

$$WACC = \frac{Debt}{Debt + Equity}\,[r_{debt}(1-T)] + \frac{Equity}{Debt + Equity}\, r_{equity}$$

$$CAPM = \quad r_{equity} = r_{free} + \beta\,(r_{market} - r_{free})$$

In the normal course of operating a company, debt is repaid in fixed instalments via interest and principal payments. Equity may be compensated through dividends, but in most cases the bulk of the financial reward will be earned through capital appreciation (an increase in the market value of the project company). When a project company becomes distressed, dividends come to a halt. Debt repayments, on the other hand, must continue. In the worst case, bankruptcy, a lender (debt) sits alongside employees, suppliers and other creditors to recover payments in a liquidation process. Shareholders (equity) are at the back of the queue and typically lose everything.

The threat of bankruptcy fundamentally shapes the risk faced by providers of debt and equity capital, and hence their required rate of return to invest. We now turn to a more technical description of the cost of capital for a new investment project.

Translating risk and return into the cost of capital

As mentioned previously, the cost of capital is determined by the project's capital structure. In corporate finance, the cost of capital is more precisely defined as the weighted average cost of capital (WACC), as in the equation below:

$$WACC = \left(C_D * \frac{D}{E+D}\right) + \left(C_E * \frac{E}{E+D}\right)$$

Where:

$C_D =$ *Cost of Debt Capital (net of tax deductions)*
$C_E =$ *Cost of Equity Capital*
$D =$ *Amount of Debt*
$E =$ *Amount of Shareholders' Equity*

The cost of debt is simply the all-in rate of interest on company loans. The cost of equity, on the other hand, is a challenging, controversial, and frequently frustrating aspect of the WACC calculation.

Two of the most well-known methods for calculating the expected return on equity are the capital asset pricing model (CAPM)[10] and arbitrage pricing theory (APT)[11].

CAPM: A single factor risk model

The CAPM is taught to nearly all aspiring finance practitioners around the world and it is cited as the most popular method amongst corporate finance directors for estimating the cost of equity[12]. It involves adding a premium to the risk-free rate, which is an increase in the required return proportionate to any additional risk incurred. Yet as indicated in the CAPM formula (below), the mathematical coefficient Beta (ß) represents the primary source of variability in the cost of equity.

Box 3: Components of the capital asset pricing model (CAPM)

Risk-free rate is a central concept in financial theory. It refers to the rate of return that can be earned by investors from investing in a risk-free asset. Yet as any finance practitioner knows, there is no such thing as risk-free asset. Every investment, no matter how safe, is subject to some element of risk. Long-term sovereign bonds (e.g. US Treasuries) are commonly used by investors as a proxy for the risk-free rate in asset pricing formulas. While volatility in the price of government bonds over recent years has called into question the very notion of a risk-free rate, the concept remains an important element of traditional approaches to asset pricing.

Equity risk premium refers to the compensation that investors require to invest in risky assets. In the CAPM, the equity risk premium can be observed by analysing the long-term differences between financial returns from government bonds and other classes of assets (e.g. equities). While the exact determinants of the equity risk premium are subject to debate, they are commonly thought to include factors like investor risk aversion, investor uncertainty, and macroeconomic indicators.

Beta (ß) is a measure of how the value of a financial asset changes in relation to the value of a portfolio of financial assets. Put more simply, we could say that Beta describes how sensitive an individual asset is to price swings in the market. As an example, a Beta coefficient of 1 indicates that, over time, an asset's price moves exactly in line with the market. Beta less than 1 indicates that asset volatility is relatively low compared to the market, while a beta of greater than 1 indicates increasing price sensitivity.

$$\beta = \frac{\mathrm{Cov}(r_a, r_b)}{\mathrm{Var}\,(r_b)}$$

The CAPM is based on a number of assumptions, most of which are violated in the real world. Investments in assets like energy infrastructure do not follow these rules because of the incomplete and heterogeneous nature of the market. Despite its limitations, the CAPM continues to be used by both academics and practitioners due to the lack of any clear successor[13].

$$CAPM = E(r_i) + \beta_i (E(r_m) - R_f)$$

where

$E(r_i) =$ required return on financial asset i
$\beta_i =$ beta value for financial asset i
$E(r_m) =$ average return on capital market
$R_f =$ risk-free rate of return

APT: A multi-factor risk model

In contrast to the CAPM, APT holds that discount rates are a function of multiple risk factors. Using CAPM, investment risk varies according to just a single ß term, whereas arbitrage pricing theory places no restrictions on the number of risk factors to be used.

$$\text{APT} = R_i = a_i + y_{i1}F_1 + y_{i2}F_2 + \ldots + y_{in} + \varepsilon_i$$

where

R_i = return on stock i

a_i = expected return on stock i (if all factors have a value of zero)

F_1 = value of jth factor (which influences the return on stock i)

y_{in} = sensitivity of stock i's return to the jth factor

ε_i = random error term

The factors of an APT asset pricing model may include generic macroeconomic indicators such as government bond rates, oil prices and various forms of inflation, as well as asset-specific risk indicators, such as liquidity. APT allows greater analyst discretion in representing the complexity of the real world of investing. This analytical discretion does, however, come with a cost – namely the loss of simplicity, replicability and standardisation.

There are a mindboggling number of models that seek to improve upon the CAPM and APT, not to mention emerging competitors to it[14]. But no matter what approach one takes to calculating the cost of equity, the basic analytical challenge remains the same. The task is first to measure risk, and secondly, to decide whether the expected financial return compensates sufficiently.

The gap between theory and practice

Empirical surveys of US and European companies indicate that corporate WACCs are generally in the range of 7-8%. Analysis of companies in the energy and natural resources sector shows the industry WACC over the past 10 years to be mostly the same[15]. These figures appear to confirm the results of theory-driven asset pricing models.

A substantial divergence between theory and practice opens up, however, with regards to the cost of capital for specific project investments. Empirical analyses have demonstrated that large, stock-market-listed companies apply investment hurdle rates that exceed their WACC by as much as 750 basis points (7.5%)[16]. Over the past 20 years, the average hurdle rate employed by large US corporations has been stable at roughly 15%17, nearly double the average corporate WACC.

Alongside the evidence that firms *overstate* hurdle rates during internal project valuations, it appears that firms frequently *understate* them as well. In one well known study, more than half of chief financial officers (CFOs) in a sample were routinely adjusting the financial value ascribed to 'strategic projects' by using a lower hurdle rate or increasing the project NPV.[18] Recent research on the German power-generation industry found firms were doing the same. The investigators found that firms were using lower hurdle rates for sensible reasons such as securing competitive resources and leveraging existing complementary assets[19]. Another study, this time covering more than 3,000 businesses in North America found that hurdle rates were both frequently below and also frequently above their WACC[20].

With all this evidence for and against, we pause to ask: *Too much, too little, or just right? Which of these stories about investment hurdle rates should we believe?*

Investment hurdle rates

Studies demonstrating upward and downward biases in hurdle rates can be drawn into a single conclusion: an investment hurdle rate (the minimum IRR required for project sanction) often bears little resemblance to the WACC.

When projects present differing levels of risk, as most real-life investment prospects do, the project discount rate should be adjusted accordingly[21]. The riskier a project's cash flows become, the higher the rate of return should be. As shown in Figure 3[22], by assigning a project-specific cost of capital to each investment, firms seek to overcome the potential errors of capital misallocation.

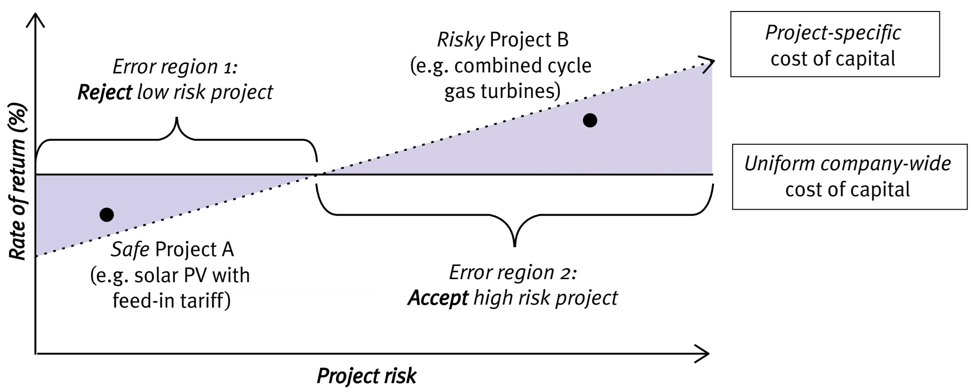


Figure 3: The relationship between company-wide and project specific cost of capital.
Source: Helms et al, 2015

In theory, firms can avoid the errors of over- and under-investment by adopting a risk-adjusted discount rate for each new investment opportunity.

In practice, many firms make adjustments to the evaluation of specific projects in order to take account of risk. But they often do so haphazardly. We see four reasons for this behaviour:

1. The crystal ball factor

A firm that faithfully follows the edicts of financial theory will quickly run into information roadblocks. The standard advice in setting risk-adjusted discount rates, to re-calibrate ß, is often useless in emerging economic sectors. It is nearly impossible to make an objective assessment of risk when there is limited historical transaction data and few comparable companies. In instances where track records are limited and the rate of technological change is highly discontinuous, historical data will offer no guidance in the task of adjusting discount rates.

2. The diverse company factor

A second source of divergence is that many firms use cost of capital estimates that are tailored to specific business divisions and/or geographical units[23]. Even a good WACC estimate for the company as a whole may be of little use to understanding the hurdle rates demanded on investments outside the company's home country or in new technological areas.

3. The diverse industries factor

Investors from specific industries approach the task of capital budgeting in a way that conforms to the norms of their industry[24]. Consider Google (a US technology company), Iberdrola (a European electric utility) and Temasek (an Asian financial institution), who are all investors in clean energy in the United States. The capital budgeting procedures each firm uses may be similar to those of competitors in their typical industry, but end up being very different from each other.

4. The sophistication factor

Finally, many firms don't use the asset pricing advocated by financial theorists at all. A recent review of past cost of capital surveys found that between 25% and 75% of companies don't use the CAPM for their cost of equity calculation; as many as half don't even calculate a WACC[25]. Generally, larger companies with stock market listings tend to follow the textbook advice. Smaller, privately-held companies do not.

How the cost of capital varies and why it matters

In global capital markets, the differences in firms' capital budgeting policies, on aggregate, don't affect the price of traded securities. But in real asset markets, these differences matter enormously – not least to policymakers seeking to set price-based incentives, such as feed-in tariffs. The anomalies of asset pricing tend to garner little attention outside academic circles but for investments in climate change mitigation it is of considerable importance to governments, investors and taxpayers. This is due to the potential for discrepancies in cost of capital estimations to negatively impact both producer surplus (electricity producer profit) and consumer surplus (the difference between the price paid for electricity and the price a consumer would have been willing to pay). These impacts on producer and consumer surplus have the potential to translate into significant social and economic welfare losses.

Building upon our previous discussion, we consider in this section how the standard model of investment decision-making is complicated by technology and by geography.

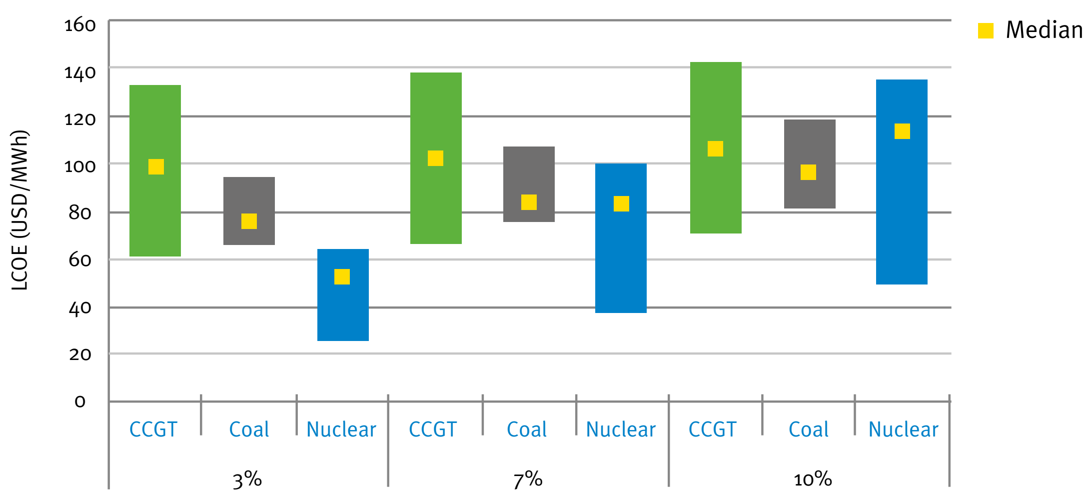


Figure 4: LCOE ranges for baseload technologies at 3%, 7% and 10% discount rates.
Source: IEA 2015

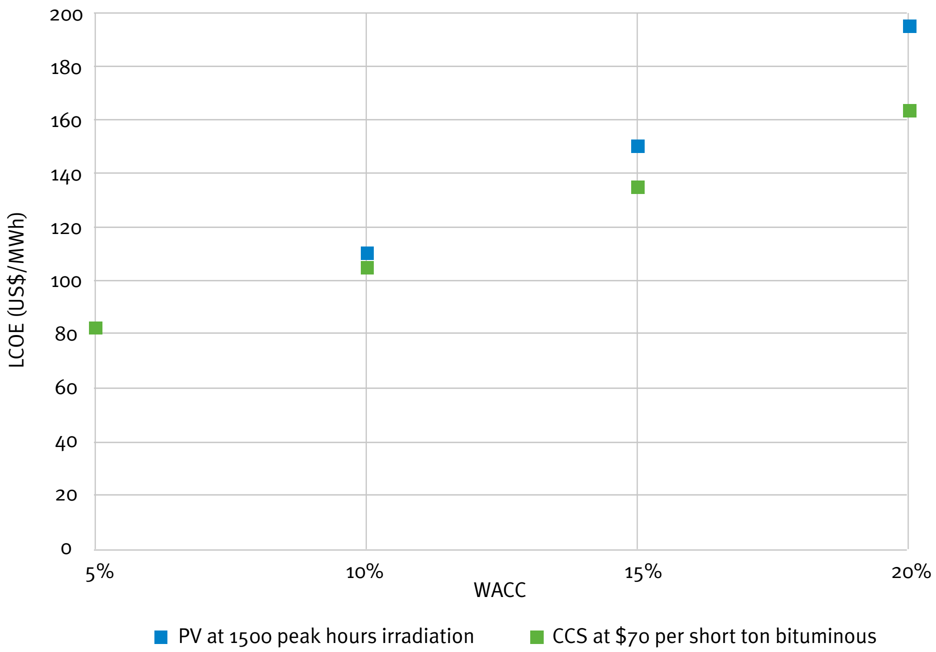


Figure 5: Impact of WACC on utility scale solar PV tariffs compared to carbon capture and storage (CCS).
Source: Authors' analysis

Variations by technology: The impact of cost of capital on the levelised cost of electricity

The levelised cost of electricity (LCOE) is a calculation used frequently by policymakers to make an 'apples for apples' comparison of the economic performance of different energy technologies. LCOE depends heavily on the discount rate employed.

A recent report by the International Energy Agency (IEA) illustrates how discount rates affect LCOE estimates for three base-load technologies: natural gas-fired closed-cycle-gas-turbines, coal and nuclear[26]. The results are reproduced in Figure 4.

Solar PV

Our model demonstrates how the price of electricity generated from utility-scale solar PV is affected by the project WACC. The model, which is illustrated in Figure 5, uses the cost and operating inputs of a typical solar PV project, assuming a lifetime of 25 years, net efficiency of 18% and an operating capacity based on an irradiation value of 1500 peak hours.

Carbon Capture and Storage (CCS)

We take a similar approach using a typical CCS investment case with a project lifetime of 25 years and fuel costs at US$70 per short ton bituminous. Our model assumes fixed operation and maintenance costs at $40,565 per megawatt (MW) and capital expenditure at $5.5million per MW.

The impact of the cost of capital on price is clear across both traditional fossil fuel (base-load) and renewable technologies. The effect is greater on technology areas that are considered riskier, or those requiring greater upfront capital investments, which can offset the cost advantages that technological progress brings.

Variations by country: Estimating country risk premiums

In international investing, the greatest influence on investment hurdle rates comes from variations in domestic interest rates. Investors tend to use domestic government bond yields as a proxy for the 'risk-free' rate when pricing capital for an investment project. As shown in Figure 6, these rates are significantly higher in developing versus developed economies.

High interest rates not only inflate the cost of loans, but also drive up the expected return on equity. To illustrate this, we show in Table 1 how variations in government bond rates and country risk premiums translate into higher financing costs in countries like South Africa and India.

If debt finance were available at terms and interest rates akin to those found in developed countries, the cost of financing renewable energy in countries such as India and South Africa could be up to 30% lower[27]. Such a reduction in the cost of financing could translate into billions of dollars-worth of savings for governments.

If India's cost of capital was akin to that of the United States for instance, up to US$5.4 billion of government expenditure on solar tariffs could be saved, while meeting the Government of India's target of 20 gigawatts (GW) of new projects by 2022. To illustrate the potential gains, that is the equivalent of building 70 new medical colleges and hospitals in India, see Figure 7[28].

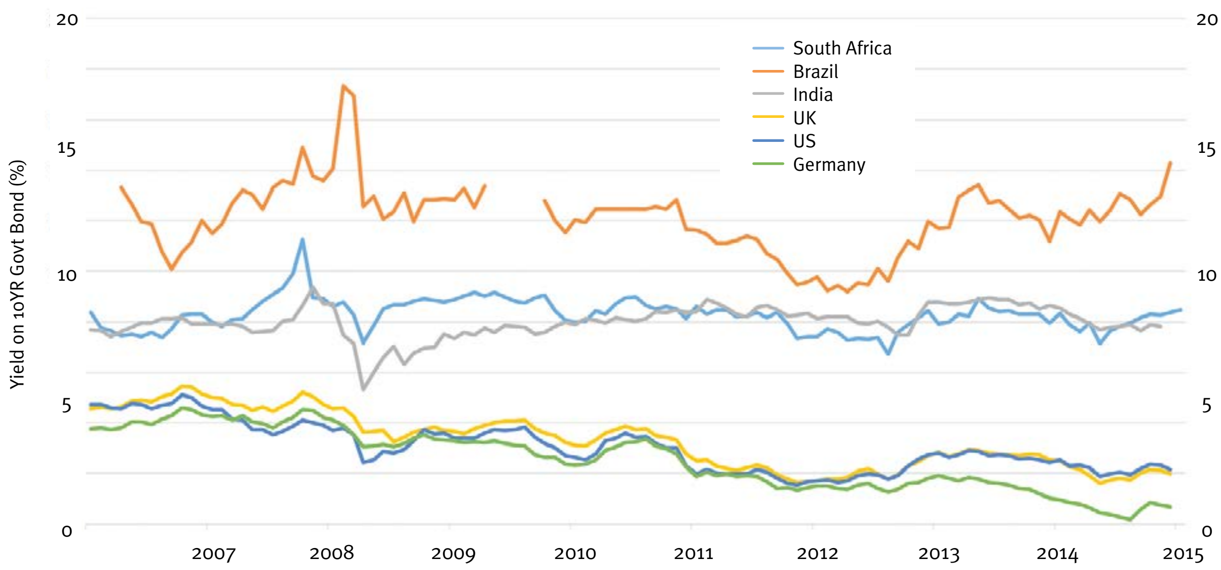
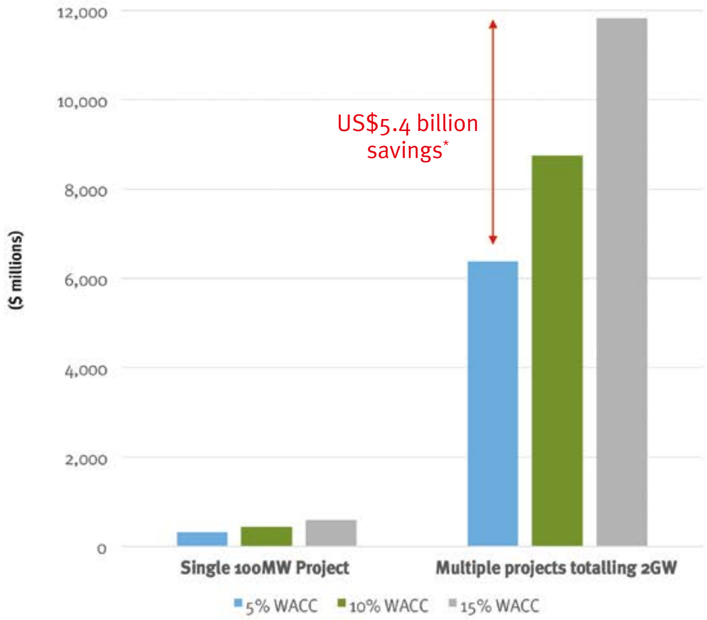


Figure 6: Historical yields on 10 year government bonds 2007-2015 (%).
Source: DataStream

Table 1: Impact of country risk premium on WACC in four countries

Country	UK	US	India	South Africa
Risk-free rate (based on 10Y government bond yield 01.09.15)	1.91%	2.41%	8.56%	8.52%
Assumed spread on loans	2.50%	2.50%	2.50%	2.50%
Cost of debt	**4.41%**	**4.91%**	**11.06%**	**11.02%**
Total equity risk premium (including default spread and country beta)*	6.20%	5.75%	9.13%	8.75%
Cost of Equity	**8.11%**	**8.16%**	**17.69%**	**17.27%**
Assumed debt-to-equity ratio	70%	70%	70%	70%
Marginal tax rate**	20%	40%	35%	28%
WACC	**4.9%**	**4.5%**	**10.3%**	**10.7%**

*Country risk premium based on data inputs provided by Damodaran, 2014[27]. **Corporate tax rate according to KPMG, 2015.



*"If the cost of the capital in India was akin to the US, the indian government could save up to US$5.4 billion on the lifetime cost of solar PV projects at scale – that is the equivalent of building 70 new medical colleges and hospitals in India**.*

*Model outputs scaled up based on US$/MWh tariffs of a typical solar PV project at different WACCs ($81/MWh at 5%, $111/MWh at 10%, $150/MWh at 15%). Assuming the PV plant operates 1500 hours per year with 18% net efficiency over 25 years.
**Based on a cost assumption of 500 crores ($70 million) per medical college and hospital.

Figure 7: Reduction in lifetime cost of feed-in tariff for solar PV projects at different investment scales (100MW and 2GW).

Challenges and opportunities for policymakers

What does this mean for government efforts to stimulate the clean-energy sector?

Some climate change policies in the energy sector attempt to stimulate action in the private sector. To do so, governments directly determine end prices, for example with feed-in tariffs, and/or creating relative price changes with taxes. To make these policies, governments need to estimate the appropriate rate of return for market participants, whose profits are supported by government price intervention. An accurate determination of the cost of capital is at the heart of this problem.

While higher WACCs clearly make renewables more costly, investment hurdle rates that are highly dispersed from an industry average also present real economic problems. Heterogeneity in investment hurdle rates complicates policymaking including the design of government price interventions such as subsidies, feed-in tariffs etc. An inherent challenge for regulators is to minimise instances in which incentives for environmental protection are too generous (offer high financial return when investment risk is low) or have no impact (offer too little financial return to trigger investment)[29].

Project-specific hurdle rates that vary widely from industry averages make the challenge of getting the level of incentive 'just right' much more difficult. Getting the level of incentive wrong simultaneously reduces both the effectiveness and cost-efficiency of government price intervention.

Governments in developing and developed countries can avoid inefficiencies caused by guesswork and miscalculation in a number of ways. The following case studies demonstrate that it is possible to offer private sector incentives without undesirable side-effects. In doing so, governments can avoid wasting taxpayer resources and more effectively stimulate investment by the private sector.

South Africa

South Africa has a high-risk free rate and a high country risk premium caused by a combination of political, economic and financial risk factors. Yet despite this translating into high financing costs, South Africa has become an attractive destination for renewable energy investment and a case study for the implementation of cost-effective policy instruments in developing countries.

Its success is largely attributable to the government's selection of competitive tenders (auctions), rather than government set feed-in-tariffs (FITs), for renewable energy. The resulting programme, known as the Renewable Energy Independent Power Producers' Programme (REIPPP), launched in 2011 and is a bidding process for the procurement of privately generated, utility-scale renewable energy. As of May 2014, 64 projects have been awarded to the private sector, receiving a total of US$14 billion in investment. These projects are currently in construction phase and set to generate nearly 4GW of renewable power[30].

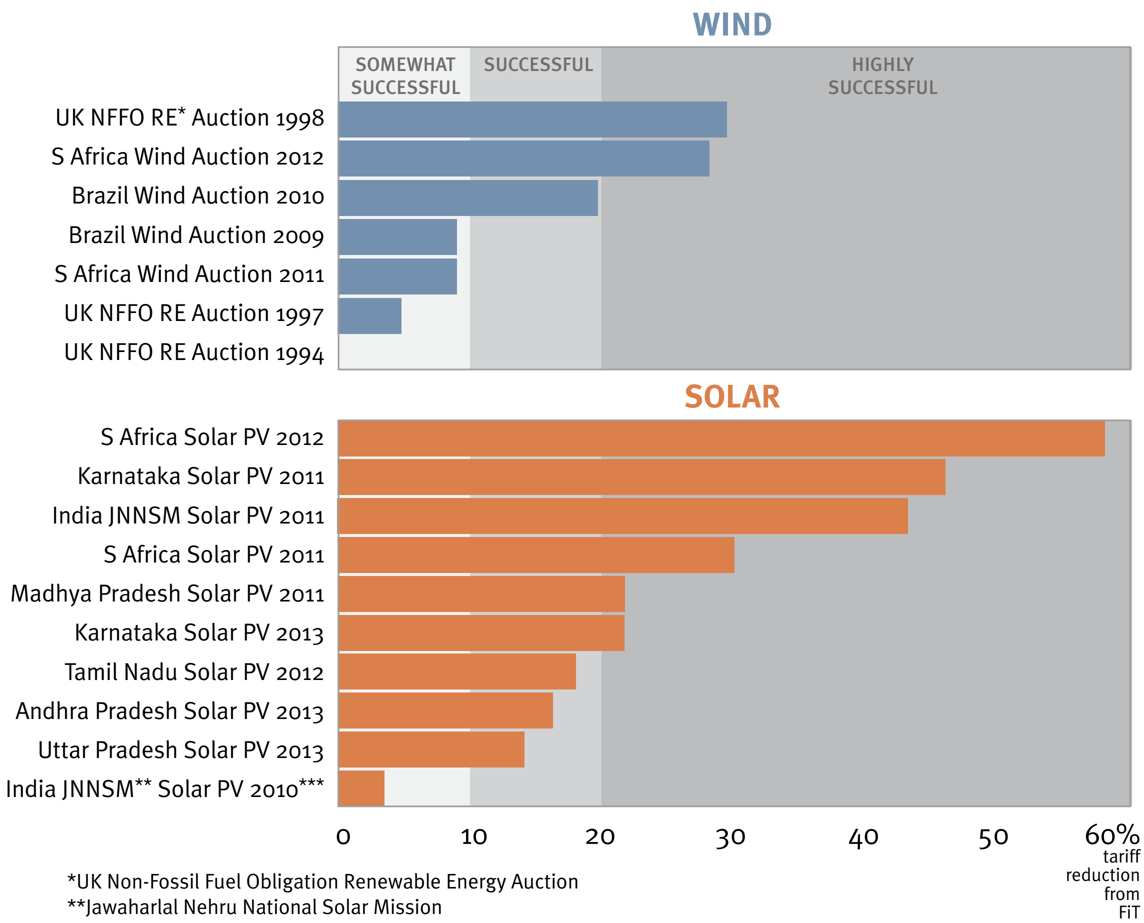
The first three rounds attracted a range of domestic and international project developers, sponsors and shareholders, comprising over 100 different shareholder entities. Private sector investors have included banks, insurers, Development Finance Institutions (DFI) and even international utilities. Most remarkably 86% of debt has been raised from within South Africa. This suggests high financing costs can be mitigated through clever policy-interventions targeting debt cost-reductions, mitigating the country risk premiums factored in by international investors.

United Kingdom

The UK's experience as a laboratory for energy policy over the past decade demonstrates the importance of a clear and effective pricing structure. The Renewables Obligation (RO) scheme launched in 2002 was a variable-price instrument. After setting annual targets for the total amount of renewable power to be generated, the value of price incentives (Renewables Obligation Certificates, or ROCs) could move up or down depending upon the supply of new renewables. Build too little (relative to the target), and the price would go up; build too much and the price would go down.

While seemingly perfect to economists, from a financial perspective the RO was highly problematic. In short, the quasi-market created by government generated too much uncertainty for investors. Due to their inability to accurately forecast ROC prices or hedge their exposure to ROC price volatility, investment hurdle rates naturally increased to reflect the risk. In the end, it was mostly large companies able to finance from their balance sheet (and being obliged to buy ROCs anyway) that could bring forward funding.

Comparing the results of the RO in the UK to the experience with fixed-price feed-in tariffs in Germany has revealed how variable price mechanisms introduce more risk to investors, thereby driving up the cost of capital for new investment projects[31]. Learning from the RO, the UK introduced in its Energy Act 2013 a new system of Contracts for Difference (CfDs). CfDs are long-term contracts intended to provide more stable and predictable incentives for companies to invest in low-carbon generation. Despite criticism regarding the introduction of the new system, there have been clear positive effects on reducing the risk profile, and subsequently the investment hurdle rates, for low carbon technologies[32].



*UK Non-Fossil Fuel Obligation Renewable Energy Auction
**Jawaharlal Nehru National Solar Mission
***Using the Gujarat feed in tariff as the baseline, the tariff reduction achieved is 3.3%
Using CFRC's benchmark tariff as the baseline, the tariff reduction is 32.3%
Source: World Bank, GERC, MNRE, Panchabuta, Economic Times, KREDL, Re-Solve. EfficientCarbon, IFC, IRENA, ANEEL, GWFC

Figure 8: Cost effectiveness of auctions (as % tariff reduction from feed-in tariffs).
Source: Shrimali, Konda, Farooquee and Nelson, 2015

India

As part of its ambitious renewable energy goals, India is aiming for 20GW of solar by 2022 and 31GW of wind by 2017. Once considered audacious, those targets are now looking very achievable given that India has recorded some of the lowest prices in the world for solar energy in 2015[33]. Indeed, India now ranks amongst the most important producers of renewable technologies worldwide and its experience has demonstrated that policy can play a major role in developing renewable energy markets.

As in South Africa, auctions are at the heart of India's success. As a policy mechanism, auctions offer regulators an opportunity to sidestep the guesswork involved in integrating the cost of capital into feed-in tariffs. Instead, by inviting the private sector into the bidding process, they are implicitly asking investors at what price they are willing to build. Regardless of technology and despite some initial resistance from developers, auctions are consistently delivering a more cost-effective solution to subsidy allocation.

Potential problems with auctions such as underbidding and completion risk can be mitigated by setting the volume of capacity auctioned within the market's ability to supply, and by imposing penalties for delays in commissioning projects[34]. Provided auctions are well-designed, they can be immensely successful in both harnessing private sector investment and eliminating the costly errors associated with guessing at the cost of capital used by investors.

Conclusions

The cost of capital directly influences the scope and scale of climate-friendly investments. We have sought to shed light on the reasons behind the following issues:

- The cost of capital is important to investment decisions taken by most firms
- It is impossible to know, *a priori*, the cost of capital ascribed to a specific investment
- The cost of capital for a specific investment opportunity will vary according to the investor, technology type, and geography
- Taxpayer resources can be wasted when investment policies rely upon regulators to estimate the cost of capital.

As has been explained in this paper, estimating the cost of capital is inherently difficult due to information asymmetries and the heterogeneity of investment methodologies used by businesses. Such guesswork can be avoided by adopting policy mechanisms that encourage investors to reveal their own cost of capital. When executed properly, these policies have huge potential to stimulate greater levels of renewable investment in both the developed and developing world.

The challenge ahead is not just to stimulate increased participation by existing investors in clean energy, but to also bring new investors into the fold. Making climate change mitigation investments available to investors as financial assets has the potential to unlock access to a US$600 trillion pool of global finance capital, nearly three times greater than the stock of real assets that underpin all economic activity in the global economy[35]. Having stable cash flows and no fuel price risk, the returns from renewable energy financial assets should be weakly correlated to the returns from the major asset classes. To financial investors, this generates a diversification benefit that will eventually translate into extraordinarily low discount rates for renewable energy projects[36]. By recognizing the potential for 'zero beta' ($\beta=0$) in renewable power project investments (i.e. returns that are unaffected by swings in the market), policymakers may find additional incentive to reduce the barriers faced by investors at the project level. The opportunity to seriously entice large institutional investors into clean energy is an opportunity that, for the sake of the planet, cannot be wasted.

Policies that reduce investment risk serve the public interest because they lead to a reduction in renewable energy tariffs, thereby minimising – to the greatest extent possible – taxpayer support for new low-carbon power capacity. Recognizing the importance of cost of capital in investment decisions, policymakers will be better prepared to promote the benefits of portfolio diversification and transfer the most costly risks away from the private sector.

References

1. Yergin, D., and J. Stanislaw. "*Commanding Heights: The Battle between Government and the Marketplace that is Remaking the Modern World.*" (1998).
2. *World Energy Outlook Special Report*, OECD/IEA, 2015. Available at: https://www.iea.org/publications/
3. Frederick, S., Loewenstein, G., & O'donoghue, T. (2002). Time discounting and time preference: A critical review. *Journal of economic literature*, 351-401.
4. More specifically, a social rate of time preference in which the pure time preference is set to zero.
5. Yale Symposium on the Stern Review (2007). *Yale Symposium for the Study of Globalization*, February 2007.
6. IRENA (2015), *Renewable Power Generation Costs in 2014*. Available at: http://www.irena.org/documentdownloads/publications/irena_re_power_costs_2014_report.pdf
7. *New Energy Outlook 2015, Powering a Changing World*. BNEF, 2015. Available at: http://www.bloomberg.com/company/new-energy-outlook/
8. The start of which is often credited to the French Mathematician Louis Bachelier for his doctoral thesis *The Theory of Speculation* in the year 1900.
9. Fernandez, Pablo. "*Betas used by Professors: a survey with 2,500 answers.*" IESE Business School, SSRN (2009): 1-12.
10. Sharpe, W.F. Capital Asset Prices: A Theory of Market Equilibrium under Conditions of risk, The Journal of Finance. Vol. 19, No. 3 (Sep, 1964) pp. 452-442; Lintner, J. The Valuation of Risk Assets and the Selection of Risky Investments in Stock Portfolios and Capital Budgets. *The Review of Economics and Statistics*, Vol. 47, No. 1 (Feb., 1965) pp. 13-37.
11. Ross, R.A., The Arbitrage Theory of Capital Asset Pricing. *Journal of Economic Theory* 13, 341-360 (1976).
12. Bruner, R.F., Eades, K.M., Harris, R.S., Higgins, R.C., Best Practices in Estimating the Cost of Capital: Survey and Synthesis. *Financial Practice and Education* Spring/Summer, 1998.
13. Fox, Justin. "*The Myth of the Rational Market: A History of Risk, Reward, and Delusion on Wall Street.*" (2009).
14. Of particular note is the Market-Based Capital Pricing Model which uses options pricing to arrive at the cost of capital embedded in the market price of a given security. It is a highly sophisticated and promising tool for use in capital markets, but of very limited use in real asset markets, such as energy infrastructure.
15. KPMG, (2014). *Cost of Capital Study 2011/2012. Developments in Volatile Markets*. Available at: http://www.kpmg.com/DE/de/Documents/Cost_of_Capital_Study_2011-2012-KPMG.pdf
16. Porterba and Summers, (1995). A CEO Survey of US Companies' Time Horizons and Hurdle Rates. *MIT Sloan Management Review*, October 15. Meier, Iwan and Tarhan, Vefa, Corporate Investment Decision Practices and the Hurdle Rate Premium Puzzle (January 28, 2007). Available at SSRN: http://ssrn.com/abstract=960161
17. Federal Reserve, 2013. *100th Annual Report. Board of Governors of the Federal Reserve System*. Available at: http://www.federalreserve.gov/publications/annual-report/files/2013-annual-report.pdf
18. Meier, Iwan and Tarhan, Vefa, *Corporate Investment Decision Practices and the Hurdle Rate Premium Puzzle* (January 28, 2007). Available at http://dx.doi.org/10.2139/ssrn.960161
19. Mullins, D. W. (1982). *Does the capital asset pricing model work*. Harvard Business Review, 60(1), 105-114.
20. Driver, C., Imai, K., Temple, P., and Urga, G. (2004). The effect of uncertainty on UK investment authorisation: Homogenous vs. heterogeneous estimators. Empirical Economics, 29(1), 115-128.
21. Copeland, T.E., Koller. T. and Murrin. J., (1990) *Valuation: Measuring and Managing the Value of Companies*, John Wiley and Sons, NY.
22. Helms T., Salm., S., Wustenhagen., (2015). Investor Specific Cost of Capital and Renewable Energy Investment Decisions in Donovan C.W. (ed.) Renewable Energy Finance: Powering the Future, Imperial College Press.
23. Bennouna, K., Meredith, G. G., & Marchant, T. (2010). Improved capital budgeting decision making: evidence from Canada. *Management decision*, 48(2), 225-247.
24. Block, S. (2003), "Divisional cost of capital: a study of its use by major U.S. firms", *The Engineering Economist*, Vol. 48, No. 4, pp. 345-362.
25. Schlegel, D. (2015). *Cost-of-Capital in Managerial Finance*. Springer.
26. International Energy Agency. 2015. *Projected Costs of Generating Electricity. Based on a study that analyzes 180 plants across 22 countries, including a carbon cost of USD $30/ton and regional variations in assumed fuel costs*. Available at: https://www.iea.org/Textbase/npsum/ElecCost2015SUM.pdf
27. Nelson & Shrimali, (2014) '*Finance mechanisms for lowering cost of renewable energy in rapidly developing countries*' (Climate Policy Initiative).
28. Damodaran, Aswath. (2012). "*Equity risk premiums (ERP): Determinants, estimation and implications–The 2012 Edition.*" March (New York City: New York University: Stern School of Business). Original data available at: www.stern.nyu.edu/~adamodar/pc/datasets/ctrypremJune13.xls
29. Lewis, T.R., 1996. Protecting the environment when costs and benefits are privately known. *The Rand Journal of Economics*; Winter 1996; 27, 4. P.819.

30. PPIAF Report: *South Africa's Renewable Energy IPP Procurement Program: Success Factors and Lessons* http://www.ppiaf.org/sites/ppiaf.org/files/publication

31. C Mitchell, D Bauknecht, PM Connor Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany. *Energy Policy* 34 (3), 297-305.

32. NERA Economic Consulting. *Changes in Hurdle Rates for Low Carbon Generation Technologies due to the Shift from the UK Renewables Obligation to a Contracts for Difference Regime*. DECC. 9 December 2013 Available at: https://www.gov.uk/government/publications/nera-economic-consulting-report-changes-in-hurdle-rates-for-low-carbon-generation-technologies

33. EY, *RECAI: Renewable energy country attractiveness index*. Issue 44. June 2015. Available at: http://www.ey.com/Publication/vwLUAssets/RECAI_44/$FILE/RECAI%2044_June%202015.pdf

34. Gireesh Shrimali, Charith Konda, Arsalan Farooquee and David Nelson. May, 2015 *Reaching India's Renewable Energy Targets: Effective Project Allocation Mechanisms.* Available at: http://climatepolicyinitiative.org/publication/

35. Bain & Company, (2012). *A world awash in money*, November 14, 2012. Available at: http://www.bain.com/publications/articles/a-world-awash-in-money.aspx

36. Awerbuch, Shimon & Yang, Spencer, 2007. "Efficient electricity generating portfolios for Europe: maximising energy security and climate change mitigation," *EIB Papers* 7/2007, European Investment Bank, Economics Department.

About the authors

Dr Charles Donovan
Charles Donovan is Principal Teaching Fellow at Imperial College Business School in London. He was most recently head of Structuring and Valuation for Alternative Energy at BP plc, where he was responsible for investment evaluation and project financings in North America, Europe, and Asia. He began his career as an energy policy analyst with the US Environmental Protection Agency during the Clinton Administration and subsequently worked for the Enron Corporation. His experience includes several years in private sector consulting, advising national governments and multinational energy companies on the impacts of governmental policy on investment. Dr Donovan holds a BA in Psychology from the University of Washington, an MBA from Vanderbilt University, and a DBA in Management from IE Business School. He is editor and co-author of *Renewable Energy Finance: Powering the Future*, published September 2015.

Christopher Corbishley
Christopher Corbishley is a PhD Candidate at Imperial College Business School funded by the Economics and Social Research Council (ESRC). His doctoral thesis focuses on the governance and coordination of energy services in developing countries, which has included a research project on building socially and economically sustainable business models for rural electrification in Africa. He is part of a multi-institutional research programme, led by Imperial College Business School and the University of Southampton Sustainable Energy Research Group (SERG), funded by the Engineering and Physical Sciences Research Council (EPSRC).

About the Grantham Institute

The Grantham Institute is committed to driving research on climate change and the environment, and translating it into real world impact. Established in February 2007 with a £12.8 million donation over ten years from the Grantham Foundation for the Protection of the Environment, the Institute's researchers are developing both the fundamental scientific understanding of climate and environmental change, and the mitigation and adaptation responses to it. The research, policy and outreach work that the Institute carries out is based on, and backed up by, the worldleading research by academic staff at Imperial.

www.imperial.ac.uk/grantham

About Imperial College London

Consistently rated amongst the world's best universities, Imperial College London is a science-based institution with a reputation for excellence in teaching and research that attracts 13,000 students and 6,000 staff of the highest international quality.

Innovative research at the College explores the interface between science, medicine, engineering and business, delivering practical solutions that improve quality of life and the environment—underpinned by a dynamic enterprise culture. Since its foundation in 1907, Imperial's contributions to society have included the discovery of penicillin, the development of holography and the foundations of fibre optics.

This commitment to the application of research for the benefit of all continues today, with current focuses including interdisciplinary collaborations to improve health in the UK and globally, tackle climate change and develop clean and sustainable sources of energy.

www.imperial.ac.uk

Annex 542

R. Kumar, *Valuation: Theories and Concepts* (Academic Press, 2016)

Estimation of cost of capital

4

4.1 Introduction

The cost of capital is generally the weighted average cost of capital. The weighted average cost of capital is the weighted averages of cost of equity and cost of debt. The cost of equity is basically determined by the capital asset pricing model (CAPM). The determinants of cost of equity are the risk-free rate, beta, and risk premium. The cost of debt can be found out using different methods.

4.1.1 Risk-free rate

Risk-free rate and risk premium are two major building blocks for the calculation of cost of equity. The risk-free rate has been dismally low during the economic recession period 2008−2009. For the calculation of cost of equity, different models like CAPM and Fama French Three factor model can be utilized. The yield-to-maturity (YTM) can be considered as risk-free rate for the application of these models. The risk-free rate consists of three components—the real return, inflation, and investment rate risk. The real rate of return is required for an investor for postponing the present consumption. Real rates of return are those rates that have been adjusted for inflation. The nominal interest rates have not been adjusted for inflation. The risk-free rate also includes the expected inflation. The expected rate of inflation is based on the period of the risk-free investment. The YTM incorporates the basic components of the risk-free rate.

The long-term US treasury bonds are considered to be default risk free, but face reinvestment risk. Bonds are sensitive to interest rate fluctuations. There is an element of uncertainty regarding reinvestment of the cash flows obtained from coupon payments and the maturity period. This can be termed as the reinvestment rate risk. The horizon premium is basically the long-term premium of government bond returns in excess of the average expected interest rates on the treasury bills. The horizon premium is expected to compensate the investor for the maturity risk of the bond.

Financial analysts use YTM of different bonds based on the period of valuation. For example, if the valuation period is 20 years, then the YTM for government bond with maturity of 20 years is used. During the 2007−2009 economic crisis period, it is found that the risk-free rates were abnormally low, which results in lower discount rate for valuation.

Academic studies have suggested that the long-term real risk-free rate of interest is estimated in the range of 1.3% to 2% based on the study of inflation swap rates and yields on long-term US treasury Inflation Protected Securities (TIPS). The average yield on long-term TIPS can be used as a proxy for long-term real rate. The average monthly 20-year TIPS yield from 2004 to 2013 period was 1.7%.

Valuation.

Table 4.1 Yield on US treasury bonds (in %) with different maturity periods

Year	10-year bond	20-year bond	30-year bond
2000	6.03	6.23	5.94
2001	5.02	5.63	5.49
2002	4.61	5.43	5.43
2003	4.01	4.96	NA
2004	4.27	5.04	NA
2005	4.29	4.64	NA
2006	4.8	5	4.91
2007	4.63	4.91	4.84
2008	3.66	4.36	4.28
2009	3.26	4.11	4.08
2010	3.22	4.03	4.25
2011	2.78	3.62	3.91
2012	1.8	2.54	2.92
2013	2.35	3.12	3.45

NA, not applicable.
Source: http://www.federalreserve.gov/releases/h15/data.htm.

Established surveys like that of Livingston survey and survey of professional forecasters conducted by Federal Reserve Bank of Philadelphia, Blue chip Financial Forecasts, University of Michigan survey have forecasted annual inflation in the range of 2.3−3%. The Congressional Budget Office in the United States have forecasted inflation of approximately 2% per annum through 2023.[1] Based on these estimates, the nominal risk-free rate can be estimated to be in the range of 3.6−5%.

Based on the historical data from Fed Reserve, it can be observed that the average YTM for 10-year US treasury bonds was *6.56%* during the period 1962−2013. The average YTM for 20-year US treasury bonds during the period 1993−2013 was *5.28%*. The average YTM for 30-year US treasury bond was *7.37%* during the period 1977−2013.[2] *The yield on long-term treasury bond can be used as risk-free rate* (Table 4.1).

4.1.2 Risk premium

The market or equity risk premium (ERP) is an important metric in finance, which is implicit in the evaluation of financing and investment opportunities. The market risk premium is the incremental premium required by investors relative to a

[1] http://appraisal.wichita.edu/2014%20Presentations/Monday/10.30%20-%20Grabowski-%20Cost%20of%20Capital.pdf.

[2] The returns calculated were arithmetic returns. The annual data for the yield to maturity for 20-year bonds were available from 1993 onward. For 30 yield-to-maturity calculation, the data were not available for period 2003−2005.The source of database was Historical statistics, http://www.federalreserve.gov/releases/h15/data.html.

risk-free asset like US government bond for the purpose of investing in a globally diversified market portfolio. The quantification of risk premium is an important step for the valuation process. The cost of equity has to be adjusted to new market realities in order to check under valuation and over valuation. In theory, stocks should provide a greater return than safe investments like treasury bonds. The difference between return on stock and risk-free rate is called the ERP. ERP is the compensation that investors require to make them indifferent between holding the risky market portfolio and risk-free bond.

Expected return on the market portfolio = Risk-free rate of return + market risk premium

Expected return on an asset = Risk-free rate of return + beta * market risk premium. In a macroeconomic perspective, the market risk premium represents the broader picture of the economy. The major factors that influence investor's perception about market risk include growth forecasts for economic growth, consumer demand, inflation, interest rates, and geopolitical risks.

The determination of risk premium is an important step in the calculation of the cost of equity. The estimation of risk premium is a function of the holding period of the investment. For the estimation of the equity return for a highly liquid investment of short-term period, the US treasury bill may be the appropriate rate to benchmark the ERP. The ERP is also known as market risk premium. ERP is the extra return over the expected yield on the risk-free securities that an investor is expected to receive from an investment in a diversified portfolio of common stocks.

Market or ERP = $R_m - R_f$

Where R_m is the expected return on a fully diversified market portfolio of equity securities. R_f is the risk-free rate. The returns on a market index like S&P 500 or NYSE Composite index is taken as a proxy for the market portfolio.

If the period stock returns are not correlated and the stock returns are quite stable, then arithmetic average of historical stock returns provides an unbiased estimate of expected future stock returns. The arithmetic average of realized risk premiums provides an unbiased estimate of expected future risk premiums. If the stock price exhibits volatility, then geometric mean of historical stock returns is a better estimate of expected future stock returns Cooper (1996). With respect to the period of estimation of risk premium, a shorter period will be susceptible to large errors in estimating its true value on account of high volatility of annual stock returns. JP Morgan estimates the risk premium within the range of 5−7% during the year 2008 (Table 4.2).

US-based market risk premium is a reasonable estimate for developed countries as unconstrained investors can freely invest in any developed economy market. But in emerging markets, US-based risk premium may not be the right choice due to nonmarket risks like political risk.

4.1.2.1 Estimation of ERP

Basically, there is no universally accepted methodology for estimating the ERP. A number of methods are used in practice and recommended by academicians and

Table 4.2 **Risk premium estimates**

Source	Risk premium estimate (%)
Historical US 1926–2007 geometric mean based on historical average realized returns	5.1
Dividend discount model	5.6
Constant sharpe ratio	6.0
Dividend yield methodology	6.6
Geometric academic survey	5
Arithmetic academic survey	5.8
Historical US 1926–2007, arithmetic mean	6.9
Implied from AA bonds	8.6

Source: JP Morgan, Corporate Finance Advisory.

financial advisors. The approaches for estimation of ERP can be classified as *ex post* approach and *ex ante* approach (Grabowski 2011). In *ex post* approaches, expected returns on common stocks are estimated in terms of averages of realized historical single period returns or multiyear compound returns. The *ex ante* approach consists of estimating the ERP using the returns on the diversified portfolio implied by the expected future stock prices or expected dividends.

Methods to estimate the market or ERP

1. Historical average-realized returns

ERP = Average annual equity index returns−average return on treasury bonds.

The choice of arithmetic or geometric method can lead to significant differences in ERP estimates. Over a long-term horizon, geometric mean is the better measure, while arithmetic average is the better estimate of annual expected return. The method can produce counterproductive results if changing risk premium environment results. In cases of increase of risk premium and constant cash flows, the equity price returns will fall. This will lead to lower realized returns which in turn would lower the average historical returns.

2. Dividend discount model

Dividend discount model (DDM) can be used to calculate the current market cost of equity. The model uses an internal rate of return (cost of equity) based on a price level and expected dividend of an index like S&P 500 as a proxy for the broad market. Dividends are projected by applying an expected payout ratio to forecasted earnings. Earnings are forecasted by combining near term of 5 years market estimates with a perpetuity growth rate equivalent to long-term nominal GDP growth. The dividend payout is initially assumed to be the average of recent historical payout ratios, but tends to increase over the long-term period toward 80% in the terminal period as reinvestment opportunities declines (Goyal and Welch 2001). It has to be noted that the market cost of equity varies primarily with movements in the level of index and changes in expectations for future dividends. DDM are forward looking and consistent with no arbitrage.

MRP = Cost of equity implied by DDM − 10-year government bond yield

3. Constant sharpe ratio method

The Sharpe ratio measures a portfolio's excess return per unit of risk.

MRP = Market (S&P 500) Sharpe ratio ∗ Market (S&P 500) implied volatility

4. Bond market implied risk premium

The bond market implied risk premium is based on the expected return on the bond and its beta. For high-yield bonds, the expected return is likely to be significantly lower than the promised yield. For AA rated corporate bond, the default probabilities are low and the yield can be used as a proxy for expected returns.

5. Dividend yield method

The dividend yield method is related to the dividend discount method. The price of the dividend paying stock can be estimated using the constant growth valuation model. The model assumes that dividend will grow at a constant rate forever. Cost of equity is the sum of dividend yield and long-term growth rates.

MRP = (Cost of equity implied by dividend yield method − 10-year government bond yield)/Beta

6. Survey evidence

Survey method is one of the basic methods used for determining the MRP. The survey results are based on the opinion of academics, investors, and CFOs.

4.1.2.2 Other perspectives on estimation of market risk premium

4.1.2.2.1 Unconditional MRP

The unconditional ERP is the long-term average ERP, which is based on realized historical risk premium data. Practitioners, tax, and regulatory authorities use historical data to estimate the conditional ERP under the assumption that historical data are a valid proxy for current investor expectations. A widely used practice is to add the same long-term average realized risk premium, which is an *ex post* estimate of the ERP to the market interest rate of the risk-free security throughout the following year, regardless of the level of the rate on that security as of the valuation date. The first assumption made in this practice is that in future period, the difference between the expected return on common stocks and US government bond is constant. The second assumption is that the increase or decrease in ERP during the valuation period is short term in nature and the ERP is mean reverting to the long-term average of the realized risk premiums within a short span of time.

Practitioners often estimate cost of capital by adding the yield on a long-term US treasury government bond to the arithmetic average of the realized risk premium each year as reported by the Morningstar SBBI Yearbook.

4.1.2.2.2 Conditional MRP

Conditional ERP is cyclical in nature and based on current market conditions. During the times of recession or near recession, returns on stock would be low and the conditional ERP would be higher. During the boom period, stock returns will be higher and the conditional ERP will be lower.

Four *ex ante* (forward looking) approaches can be used to estimate the conditional ERP. They are bottom-up implied ERP estimates, top-down ERP estimates, top-down risk premium estimates, and survey approaches. In bottom-up implied approach, the expected growth in earnings or dividends forms the basis for estimating a "bottom-up" company by company rate of return for the companies. The top-down implied ERP estimate uses expected growth in earnings or dividends for the aggregate of the companies comprising a stock index. The top-down risk premium estimates uses the ERP or changes in ERP using the observed relationship between interest rates and other factors, which impact the ERP. Survey method relies on the opinions of investors and financial professionals about the risk premiums. Professor Damodaran (2006) calculates the implied ERP estimates for the S&P 500 data using a multistage model. Duff and Phelps recommends ERP of 5% and an expected (normalized) risk-free rate of 4% as of December 31, 2013.[3]

4.1.2.3 Research discussions on ERP

The existing empirical research that investigates the size of equity premium is generally based on the mean difference between an estimate of the return to holding equity and the risk-free rate. Goyal and Welch (2008) suggest that historical mean is a good tool for forecasting the equity premium. Siegel (1999) predicted that the ERP will decrease on account of low current dividend yields and high equity valuations.

Campbell and Shilier (2001) forecasted low returns due to the perception that the market was overvalued. Amott and Ryan (2001) suggested that the forward-looking ERP is actually negative. Arnott and Bernstein (2002) argued that the forward-looking ERP is near zero or negative.

Many studies suggest that long-term predictability is much better than short-term predictability. The implied forward looking estimates of ERP can be estimated on the basis of underlying expectations of growth in corporate earnings and dividends using the *ex ante* approach. Fama and French (2002) estimate the equity premium using dividend and earnings growth rates to measure the expected rate of capital gain. The study based on a very long period of 1872−1999 estimated a historical expected geometric equity premium of 2.55 percentage points when they used dividend growth rates and a premium of 4.32 percentage points on the basis of earnings growth. The study observed that the increase in the price earnings ratio would have resulted in a realized ERP, which was higher than the *ex ante* (expected) premium. Robert (2001) suggests that the expected ERP can be estimated on the basis of a normal or unconditional ERP (the long-term average) and a conditional ERP based on the current level of the stock market and economy relative to the long-term average. Kozhan et al. (2013) find that the skew premium accounts for over 40% of the slope in the implied volatility curve in the S&P 500 market. Skew risk is tightly related to variance risk. Elroy et al. (2003) examined the realized equity returns and equity premiums for 17 countries during the period 1900−2009. The study observes that larger equity returns were obtained in the second half of the twentieth century compared to the earlier period. This pattern was basically due to growth of corporate cash flows, lower transaction and monitoring costs, lower inflation rates and lower required rates of returns as expected by investors on account of decreased investment risks. The study also observes that increases in overall price to dividend ratio are on account of the long-term decrease in the required risk premium. Ibbotson and Chen (2003) find that the expected long-term ERP relative to the

[3] Valuation Handbook-Guide to Cost of Capital. Duff & Phelps.

long-term government bond yield is 6 percentage points in terms of arithmetic mean and 4 percentage points in geometric mean terms.

Survey-based studies generally support higher ERPs. Welch (2000) conducted a survey of 226 academic financial economists to elicit their view on ERP and forecasted a geometric long horizon ERP of approximately 4 percentage points. Graham and Harvey (2001) based on multiyear survey of chief financial officers of US companies suggest expected 10-year geometric average ERP in the range of 3.9 to 4.7 percentage points.

Studies have also documented long-term average or unconditional estimate of ERP. Shannon et al. (2010) observes the long range of conditional ERP estimates over the entire business cycle is in the range of 3.5−6.0% during the period 1926−2010. This study documents realized risk premiums of 6.72% during the period 1926−2010.

Academic studies indicate that ERP are lowest in periods of business expansion and highest in periods of recession. Fabio (2002) finds that ERP is positively correlated with long-term bond yields and with default premium measured as the differential rates between Aaa- and Baa-rated bonds. Mayfield (2004) suggest that the required market risk premium for the period after 1940 is 5.9% over the yield on treasury bills. Harris and Marston (1999) find an average market risk premium of 7.14% above yields on long-term US government bonds over the period 1982−1998. Fernando and Carlos (2013) estimate the ERP by combining information from 20 models and point that equity premium reached historical heights in July 2013 at 14.5%, the highest level in 50 years. The study also states that the ERP during the financial crisis in 2009 was 10.5%.

4.1.2.4 Variations in risk premium estimations

The variations in historical risk estimates by different estimators are due to differences in time period used, the choice of bonds or bills of different maturity as the risk-free rate, and the usage of arithmetic averages compared to geometric averages. There are estimates for historical risk premium, which are based on long time period from 1926 onward. At the same time, risk estimates are also based on shorter time period of 10, 20, or 50 years. Hence, the risk estimates are of different values. The disadvantage of using longer period is that the risk perception of the investor changes over the period of time. If shorter periods are used, greater standard errors in the estimation is found. For example, the annual standard deviation in stock prices between 1926 and 2010 was found to be 20%. The calculation of standard error of the estimate for 5 and 50 years comes to 8.94% $(20\%/\sqrt{5})$ and 2.83% $(20\%\sqrt{50})$, respectively. The choice of treasury bill or treasury bond as the risk-free asset is also a factor for variation in the estimated values for risk premium. If the risk-free asset is taken as treasury bills, then the difference between the average return on stocks minus the yield on treasury bill is calculated for the risk premium. If the treasury bond rate is considered as the risk-free rate, then the difference between average return on stocks minus the yield on treasury bond rate is used as the risk premium. The two standard statistics used for estimating historical average return on the stocks are the arithmetic and geometric mean. The results vary based on these two estimates. For example, Professor Damodaran (2012) estimates the arithmetic mean of stock returns (based on S&P 500 returns) and 10-year treasury bond returns as 11.5% and 5.21%, respectively, during the period 1928−2013. This results in a risk premium of 6.29% from arithmetic mean calculations. During the same period, the geometric mean-based returns on stock and bond were 9.55% and 4.93% resulting in a risk premium of 4.62%. During the period 2004−2013, the arithmetic mean-based risk premium was 4.41%, while the geometric mean-based risk premium was 3.07%.[4] The arithmetic mean or the simple average is the unbiased measure of the expected value of repeated observations of a random variable. Hence, arithmetic return is the rate of return that investors expect over the next year for the random annual rate of return on the market. Geometric average is the compounded annual growth rate or time weighted rate of return. The use of the arithmetic mean ignores the estimation error and serial correlation in returns.

There is a paradox in the fact that if we consider a long-term period for historical risk premium estimation, then the risk assumptions would have undergone changes during the long period. At the same time, if we use a short period, the challenge would be to deal with large standard error associated with the risk premium estimates on account of stock volatility.

4.1.2.5 Risk premiums in other markets

The study by Elroy et al. (2011) provide global evidence on the long-term realized equity premium relative to both bills and bonds in 19 different countries. The study suggests considerable variation in risk premiums across countries. The study finds that the mean real returns were an annualized 5.5%, and the equity premium relative to the long-term government bonds was an annualized 3.8%. The dataset was based on two North American markets, eight euro currency markets, five other European markets, three Asia pacific market, and one African market region (Table 4.3).

The risk premium in other markets like emerging countries can be calculated by adding a country premium to the base premium of the developed market.

ERP = Base premium for matured developed equity market + country risk premium.

4.1.2.5.1 Estimation of country risk premium from default spread

The country risk premium can be estimated based on the default spread on country bonds issued by the emerging country and equity market volatility. Credit rating agencies like S&P, Moody's Investors Services, and Fitch provide sovereign ratings for all countries. These ratings that measure the default risk of a country is based on a number of factors like political stability, trade balances, and stability of national currency. These sovereign ratings can be used to estimate the default spreads over the riskless rate. The S&P gave a rating of BBB− to Brazil's long-term foreign currency sovereign credit rating in November 2014. This rating suggested a stable outlook, which reflected

[4] Annual Returns on Stocks, T. Bonds and T.Bills :1928-Current, http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/histretSP.html.

Table 4.3 Risk premium relative to bonds (1900−2010)

Country	Geometric mean (%)	Arithmetic mean (%)
Australia	5.9	7.8
Belgium	2.6	4.9
Canada	3.7	5.3
Denmark	2.0	3.4
Finland	5.6	9.2
France	3.2	5.6
Germany	5.4	8.8
Ireland	2.9	4.9
Italy	3.7	7.2
Japan	5.0	9.1
The Netherlands	3.5	5.8
New Zealand	3.8	5.4
Norway	2.5	5.5
South Africa	5.5	7.2
Spain	2.3	4.3
Sweden	3.8	6.1
Switzerland	2.1	3.6
United Kingdom	3.9	5.2
United States	4.4	6.4
Europe	3.9	5.2
World ex USA	3.8	5.0
World	3.8	5.0

Source: Elroy, Dimson, Paul Marsh, Mike Staunton, Triumph of the Optimists, Princeton University Press 2002; Credit Suisse Global Investment Returns Year book 2011.

the Brazil's institutional and balance sheet strength. Moody services gave a bond implied rating of Baa3 in October 2014. The yield on Brazilian government bond with 10-year maturity was 12.29% in November 2014. The average yield on US government bond with 10-year maturity was 6.37%.[5] The average yield on Brazil government bond with 10-year maturity was 12.27%. Brazil's dollar bonds yield an average 2.05 percentage points more than US Treasuries, compared with 2.30 percentage points at the end of 2013, according to index data from JP Morgan Chase & Co.[6] The default spread is found out as the difference between the yield on dollar denominated Brazil government bond and US government bond with same maturity period. In this case, it is found to be 8.42−6.37 = 2.05%. The standard default spread with BBB− /Baa3 rating for 30-year maturity bond is 2.04 as of November 2014 (Table 4.4). The cost of equity estimated in dollars for a Brazilian company in dollar terms can be calculated as follows :

Cost of equity (in US dollars) = (US risk-free rate + beta ∗ US risk premium) + default spread

[5] http://www.tradingeconomics.com/united-states/indicators.

[6] http://www.bloomberg.com/news/2014-07-23/brazil-planning-to-sell-benchmark-dollar-bonds-maturing-in-2045.html.

Table 4.4 Reuters corporate spread table for industrials in percent (as of November 7, 2014)

Rating	5 Year	10 Year	30 Year
Aaa/AAA	0.18	0.42	0.65
Aa1/AA+	0.34	0.54	0.77
Aa2/AA	0.50	0.65	0.89
Aa3/AA−	0.54	0.69	0.92
A1/A+	0.58	0.72	0.95
A2/A	0.61	0.77	1.03
A3/A−	0.72	0.89	1.17
Baa1/BBB+	0.92	1.15	1.51
Baa2/BBB	1.07	1.32	1.70
Baa3/BBB−	1.40	1.65	2.04
Ba1/BB+	2.17	2.48	2.86
Ba2/BB	2.95	3.30	3.67
Ba3/BB−	3.72	4.13	4.49
B1/B+	4.50	4.95	5.30
B2/B	5.27	5.78	6.12
B3/B−	6.04	6.60	6.93
Caa/CCC+	6.82	7.43	7.7.5
US treasury yield	1.74	2.73	3.35

Source: http://www.bondsonline.com/Todays_Market/Corporate_Bond_Spreads.php. Bonds Online Group, Thomson Reuter.

Consider the following inputs. Beta for the company = 1.5, US treasury bond rate (risk-free rate) = 6.37%, US risk premium = 4.4 %, Default spread for Brazil = 2.05%.

Cost of equity for Brazil company in US dollars = [6.37 + 1.5 ∗ 4.4] + 2.05 = 15.02%

The cost of equity for the company in Brazilian currency can be estimated by relative inflation. The inflation rate in Brazil in September 2014 was 6.75%, and the inflation in the United States was 1.7% in September 2014.

$(1 + \text{Expected cost of equity}_{\text{Home country}}) = (1 + \text{Expected cost of equity US}) * [1 + \text{inflation rate in home country}/1 + \text{inflation rate in US}]$

$\text{Expected cost of equity}_{\text{Home country}} = 1.1502 * [1.0675/1.017] - 1 = 0.2073$ or 20.73%.

The spread values represent basis points (bps) over a US treasury security of the same maturity, or the closest matching maturity. Suppose a corporate bond has obtained a credit rating from Moody/S&P of value Ba3/BB−. Then the interest rate on the bond is calculated as the US treasury yield for the 10-year bond plus the default spread. In this case, it equals 2.73 + 4.13 = 6.86%. The default spread can vary for bonds with same rating but different maturity periods. The default spread is found to increase during periods of low economic growth.

4.1.2.5.2 Country risk premium from volatility of stock prices

Country risk premium can also be estimated from volatility of stock prices. The equity risk is measured by the standard deviation in stock prices. Relative standard deviation of stock prices in emerging country is found out in relation to standard deviation of stock prices in the US market. Then the ERP in the emerging market is obtained as the product of risk premium in the United States and the relative standard deviation of stock prices in the United States. Another alternate approach is based on the implied equity premiums.

4.1.2.5.3 Estimation of default spread from bonds

The default spread for each ratings can be based on the sample bonds within that ratings class and obtain the current market interest rate on these bonds. The sample of bonds are required as single bonds may be mispriced or misrated. The two measures to estimate the interest rate on bond are the current yield on the bond and YTM. The current yield on the bond is the bond's annual coupon divided by its market price. The YTM is the rate required in the market on the bond. YTM is the interest rate that makes the present value of the coupons and the face value of the bond equal to the market price. YTM is considered to be a superior measure of market rate of interest.

4.1.3 Estimation of cost of equity

The cost of equity is estimated by means of standard risk return model of CAPM. The risk and return models are discussed in detail in Chapter 2. All models have two important components—the risk-free rate and risk premium.

Expected return = Riskless rate + beta * (risk premium)

4.1.4 Beta estimation

The beta can be estimated through historical market beta, fundamental beta, and accounting betas.

4.1.4.1 Historical beta estimation

Historical beta is estimated by regressing the stock returns on the market returns during the estimation period. Estimation of historical returns are based on a period of daily, weekly, or monthly returns. The market index returns are obtained from stock index like S&P 500, DJIA, or NYSE Composite Index.

$\text{Stock return}_t = \text{Price}_t - \text{Price}_{t-1} + \text{Dividends}_t/\text{Price}_{t-1}$

Where Stock return_t is the return to the stockholder in time period t

- Price_t is the price of the stock in time period t
- Price_{t-1} is the price of the stock in time period $t-1$
- Dividends_t is the dividend per share given in time period t

The returns on the market index like DJIA are estimated as given below:

$\text{Market return}_t = \text{Index}_t - \text{Index}_{t-1} + \text{Dividends}_t/\text{Index}_{t-1}$

where Market $return_t$ is the return on the market index at time period t

- $Index_t$ is the value of index during the time period t
- $Index_{t-1}$ is the value of index during the time period t − 1

The expected return R_i on a stock according to CAPM is given by

$$R_i = R_f + \beta(R_m - R_f)$$
$$R_i = R_f + \beta R_m - \beta R_f \text{ Rearranging we get}$$
$$R_i = R_f(1 - \beta) + \beta R_m$$

This expected return can be compared to the returns from the regression obtained. That is

$$R_i = a + bR_m$$

The slope of regression b corresponds to the beta of the stock, which measures the systematic risk of the stock. The comparison of the regression intercept a to R_f $(1 - \beta)$ provides the measure of stock performance in relation to the CAPM. The difference between *a* and the measure R_f $(1 - \beta)$ is called Jensen's alpha. Jensen's alpha, or *ex post* alpha, is determined by taking the current portfolio return and subtracting the expected return according to the CAPM. The difference between a and R_f $(1 - \beta)$ provides a measure of whether the investment earned a return greater than or less than its required (expected return) as estimated from the CAPM model.

If $a > R_f\ (1 - \beta)$, then the stock has greater return than expected during the regression period
If $a = R_f\ (1 - \beta)$, then the stock has return equal to the expected return during the regression period
If $a < R_f\ (1 - \beta)$, then the stock has return less than the expected return during the regression period

R-squared (R^2) provides the measure of goodness of fit for the regression, which is an estimate of the proportion of risk of a firm which can be attributed to market risk and then balance $(1 - R^2)$ can be attributed to firm-specific risk. The standard error indicates the amount of error in the estimate.

Beta estimation services are provided by Merrill Lynch, Barra, Value Line, Standard & Poor, Morning Star, and Bloomberg. Bloomberg provides an adjusted beta which is obtained by the raw beta $* 0.67 + 1.00 * 0.33$. The values obtained for beta estimation varies based on the length of the estimation period, return interval, and choice of market index to be used for the regression analysis. Service firms usually uses 5- or 2-year data. Longer the estimation period the more data would be available for analysis, but the risk characteristics of the firm would have undergone changes during the long estimation period. The stock and market index returns can have intervals like annual, monthly, weekly, and daily returns. The usage of daily returns increases the number of observations in the regression, but at the same time exposes the estimation process to significant bias in beta estimates due to nontrading. The choice of market index must be related to the stock market in which the stock is listed. The market index for US stocks could be NYSE composite index, Dow Jones Industrial Average, and S&P 500 index. The beta of Japanese stocks can be estimated relative to Nikkei and British stocks relative to FTSE index.

4.1.4.1.1 Regression beta calculation

This section describes the beta calculation for three automobile companies one from the mature market and two from the emerging market. The stocks selected were General Motors from US, Tata Motors from India, and SAIC Motor Corporation from China. The S&P 500 index was chosen as the market index for General Motors. The BSE SENSEX and SSE Composite (also known as Shanghai Composite) was the market index chosen for estimation of beta for Tata Motors and SAIC Motor Corporation Group, respectively. The beta estimation was based on a 5-year period (October 2009−2014) with monthly returns interval.

Beta estimate for General Motors with market index S&P 500.

The slope of the regression is 1.71 which is the beta for the stock. The adjusted R^2 value of 0.4046 indicates that 40.46% of the variation comes from market sources and the rest from firm specific source. The standard error of the estimate is 0.068, which gives the beta range of 1.64 to 1.78 at 95% level of confidence.

Regression statistics

Multiple R	0.65
R^2	0.42
Adjusted R^2	0.40
Standard error	0.068
Observations	47

Similarly, the beta for Tata Motors was estimated as 1.58. The beta for SAIC Motors was 0.41 during the estimation period. The data and procedure for beta calculation are illustrated in the resources excel worksheet *beta calculation for GM TATA SAIC.xlsx*. Beta estimated from regression may have high standard errors.

4.1.4.2 Fundamental beta estimation

The historical method of beta estimation is possible only for firms which are traded and have market prices. Fundamental beta estimation method is utilized for estimating betas for private firms.

4.1.4.2.1 Fundamental beta

Fundamental beta is basically used to calculate the beta of the unlisted firms. Fundamental beta is the product of a statistical model, which can be used to predict the fundamental risk of a security using market related and financial data. Fundamental beta is an alternative to statistical beta. Fundamental beta is based on fundamental factors, which drives risks to cash flow. The major determinants of fundamental betas are company size, the degree of operating leverage, and the firm's financial leverage.

4.1.4.2.2 Determinants of beta

Nature and size of businesses

Smaller firms are assumed to have more uncertain future cash flows and hence higher betas than larger firms. The beta for a firm would be higher if it is more sensitive to market conditions. Cyclical firms are considered to have more beta than uncyclical firms. Real estate and automobile firms have higher betas, whereas food and tobacco firms have lower betas. Firms with discretionary products are found to have higher beta than firms, which sell essential consumer products. Tiffany will have a higher beta than Procter and Gamble. The elasticity of demand is also a determinant of fundamental beta. The more elastic the demand for a product of a firm, the higher would be the beta of the firm. Inelastic demand for a firm's products leads into lower beta. More competition leads to higher uncertainties for future cash flows and results in higher betas.

Degree of operating leverage

Fixed costs acts as a fulcrum in the case of operating leverage. Higher the fixed costs in relation to total costs, higher would be the operating leverage. The variability of operating income would be high for firms with high operating leverage. Firms with high operating leverage tend to have higher beta values.

The degree of operating leverage is given by

Degree of operating leverage = Percent change in operating profit/percent change in sales

Financial leverage

Another major determinant of fundamental beta is financial leverage. Higher the financial leverage, riskier the firm will be and greater would be the beta of the firm. A firm with higher leverage faces uncertainty in periods of greater variability in cash flows. A firm with higher financial leverage have greater outflows in the form of fixed interest payments. Hence, the equity risk of the investment rises and beta would be higher. An all equity firm have only unlevered beta, which is also known as asset beta. Asset beta is determined by the assets owned by the firm. The unlevered beta is determined by the size and type of businesses and degree of operating leverage. The levered beta signifying equity investment in a firm is determined by all the factors like type of businesses, operating leverage, and financial leverage of the firm.

The relationship between levered and unlevered beta is given by the following equation

$$\beta_L = \beta_u(1 + (1 - t)D/E)$$

where β_L is the levered beta for equity in the firm.

β_u is the unlevered beta of the firm (beta of firm with no debt in capital structure), t is the corporate tax rate, and D/E is the debt equity ratio.

4.1.4.2.3 Bottom-up approach for beta estimation

Bottom-up approach method is used to calculate beta values for startup firms and private companies that do not trade in the stock market. The bottom-up beta method depends on the major determinants like the nature of business the firms are in; the operating leverage of the firm; and the financial leverage of the firm. The bottom-up beta is estimated by the weighted average of the unlevered betas of the different businesses that the firm operates in.

Regression betas estimated from historical stock have high standard errors. The historical beta obtained from regression does not reflect the current mix of the business mix and represent the firm's average financial leverage over the period rather than current leverage.

A bottom-up beta is estimated from the betas of firms which are in a specified business. The procedure eliminates the need for historical stock prices to estimate the firm's beta. Hence, the standard error due to regression betas is reduced to a great extent. The problem of changing product mix is eliminated as the business finds a cost of capital for each product line. The leveraged beta is computed from the company's current financial leverage than the average leverage over the period of the regression. Bottom-up beta is considered to be a better measure of the market risk associated with the industry or sector of the business. Bottom-up betas capture both the operating and financial risk of a company.

4.1.4.2.4 Steps in bottom-up beta estimation

- Identify the business or businesses in which the firm operates
- Find sample of publicly traded firms for each of these businesses and find their regression betas. Then an average beta for these publicly traded firms is found out. This average beta is unlevered using the average debt equity ratio of the publicly listed firms in the sample.

$$\beta_u = \text{Average } \beta_L / (1 + (1 - t)\text{Average } D/E)$$

- Estimate the unlevered beta for the target firm selected for analysis by the simple average of the unlevered betas for the comparable firms if the firm is in a single business. If the target firm is in multiple businesses, then the weighted average of the unlevered betas of the businesses in which the firm operates is found out. The weights can be based on value, operating income, or revenues. The weighted average is the bottom-up unlevered beta.
- The levered beta for the firm is obtained by using the current debt equity ratio of the firm based on market values.

The cash adjusted beta can be obtained from the following equation

Cash-adjusted beta = Unlevered beta/(1 − cash/firm value)

The standard error of the bottom-up beta is given by the following equation (Table 4.5)

Standard error = Average standard error of comparable firms/square root of number of comparable firms.

Table 4.5 Estimation of bottom-up beta for Walmart in 2013

Companies	Beta	D/E (%)	Tax rate
Big lots	1.31	6.87	0.33
Home depot	1.02	146.08	0.36
Target	0.94	86.34	0.36
Safeway	1.07	68.41	0.27
The Kroger	0.97	223.02	0.33
Costco	0.57	41.47	0.32
Family dollar	0.41	46.87	0.36
Dollar General	0.93	58.58	0.37
Dollar Tree	0.65	52.28	0.37
Amazon	1.19	29.42	0.32
Average	0.906	75.934	0.34

The average beta for the comparable firms is 0.906. The average debt equity ratio was 0.759. The average tax rate was 34%.

The unlevered beta is obtained from the following equation.

$$\beta_L = \beta_u(1 + (1 - t)D/E))$$

Using average tax rate of 34% and average debt equity ratio of 0.759, the value of unlevered beta is obtained.

$$\begin{aligned}\beta_u &= \beta_L/(1 + (1 - t)D/E) \\ &= 0.906/(1 + (1 - 0.34) * 0.759 = 0.6036\end{aligned}$$

The levered beta for Walmart is obtained by using the Walmart's marginal tax rate of 0.31 and debt equity ratio of 0.66 in 2013.

$$\begin{aligned}\beta_L &= \beta_u(1 + (1 - t)D/E)) \\ &= 0.6036(1 + (1 - 0.31) * 66) = 0.87.\end{aligned}$$

4.1.4.3 Accounting betas

Accounting betas are estimated by regression of the company's return on assets against the average return on assets for large sample of firms as included in a market index. Betas determined by using accounting data instead of stock market data is known as accounting data. Accounting betas can also be found out by regressing changes in earnings for a firm with respect to changes in earnings of market over a period of time. Estimation of accounting betas using regression involves only few observations which would result in more standard errors. Moreover, accounting earnings are affected by other factors like changes in depreciation or inventory methods.

4.1.5 Cost of equity

The cost of equity or expected rate of return can be estimated using risk and return models like CAPM, Arbitrage Pricing, and Multifactor Model. CAPM is the most popular method adopted by practitioners.

Expected return = Riskless rate + beta * expected risk premium

The rate on the long-term government bond is the riskless rate and the beta can be estimated using historical beta method or fundamental bottom-up method. The risk premium could be either historical risk premium or an implied risk premium.

4.1.6 Cost of capital

The cost of capital basically refers to the weighted average cost of capital.

The first step involved in the calculation of cost of capital is the cost of equity calculation. The next step involved is the cost of debt calculation. The cost of debt refers to the cost of borrowing funds. The cost of debt indicates the default risk of the debt. The cost of debt is determined by the riskless rate, the default risk, and the tax advantage on account of using the debt. The after tax cost of debt is given by Pretax cost of debt (1 − t).

4.1.6.1 Cost of debt calculation

Cost of debt can be estimated using one of the following methods:

If the firm has outstanding bonds that are traded, then the YTM on a long term bond can be used as the cost of debt.

If the firm's bonds are not actively traded, then the cost of debt for the firm can be estimated using the ratings of the firm and the default spread. Suppose a firm obtained a Baa3/BBB− rating by the Moody's/S&P. The default corporate spread is given as 204 basis point(bps) for a 30-year bond. 1% is equal to 100 bps. The US treasury yield for 30-year treasury bond is given as 3.55%. We need to add 204 basis spread to the US treasury yield of 3.55% to get the cost of debt for the firm. In this case, the cost of debt comes to (3.55 + 2.04) = 5.54%. Suppose the tax rate for the firm is 30%, then the after tax cost of debt = 5.54(1 − 0.30) = 3.878. Refer Table 4.6 for default spreads.

If the firms are not rated, then synthetic ratings can be used to estimate the cost of debt. The firm is assigned a rating based on its financial ratios. For example, a low market cap firm with interest coverage ratio of >12.5 gets a ratings of AAA while <0.5 gets a rating of *D* based on S&P ratings. Interest coverage ratios tend to be lower for large market capitalization stock. A large market cap stock firm with ICR of >8.5 gets a AAA rating while <0.2 gets a D rating. Based on the synthetic rating, the default spread can be added to the risk-free rate to get the pretax cost of debt for the firm.

Another method is to identify the current cost of the company's debt which is the interest rate the company would pay on the new debt. The interest expense obtained from the income statement divided by the total long-term debt gives the cost of debt.

Table 4.6 **Reuters corporate spreads for industrials March 2014**

Rating	1 Years	2 Years	3 Years	5 Years	7 Years	10 Years	30 Years
Aaa/AAA	5	8	12	18	28	42	65
Aa1/AA+	10	18	25	34	42	54	77
Aa2/AA	14	29	38	50	57	65	89
Aa3/AA−	19	34	43	54	61	69	92
A1/A+	23	39	47	58	65	72	95
A2/A	24	39	49	61	69	77	103
A3/A−	32	49	59	72	80	89	117
Baa1/BBB+	38	61	75	92	103	115	151
Baa2/BBB	47	75	89	107	119	132	170
Baa3/BBB−	83	108	122	140	152	165	204
Ba1/BB+	157	182	198	217	232	248	286
Ba2/BB	231	256	274	295	312	330	367
Ba3/BB−	305	330	350	372	392	413	449
B1/B+	378	404	426	450	472	495	530
B2/B	452	478	502	527	552	578	612
B3/B−	526	552	578	604	632	660	693
Caa/CCC+	600	626	653	682	712	743	775
US treasury yield	0.13	0.45	0.93	1.74	2.31	2.73	3.55

Spread values represent basis points (bps) over a US treasury security of the same maturity, or the closest matching maturity.
Source: Bonds Online Group, Thomson Reuter.

After-tax cost of debt = Pretax cost of debt (1 − T) where T is the tax rate.

The cost of debt in an emerging market company can be estimated by adding the country default spread based on sovereign rating for the country in which the firm is domiciled to the company default spread based on synthetic rating and the risk-free rate.

Cost of debt for emerging market company = Riskless rate + country default spread + firm default spread.

The firm default spread can be based on the ratings obtained by the firm on its long-term bond issue given by S&P or Moody's or synthetic rating (Tables 4.7−4.10).

4.1.6.2 Cost of preferred stocks

The cost of preferred stock is given by

Preferred dividend per share/Market price per preferred share.

The cost of other hybrid securities like convertible bonds can be estimated. The hybrid components can be broken down into debt and equity components and cost can be found out separately.

Table 4.7 Business and financial risk profile matrix

Business risk profile	Financial risk profile					
	Minimal	Modest	Intermediate	Significant	Aggressive	Highly leveraged
Excellent	AAA/AA+	AA	A	A−	BBB	−
Strong	AA	A	A−	BBB	BB	BB−
Satisfactory	A−	BBB+	BBB	BB+	BB−	B+
Fair	−	BBB−	BB+	BB	BB−	B
Weak	−	−	BB	BB−	B+	B−
Vulnerable				B+	B	B− or below

Source: Mark Puccia, Methodology: Business Risk/Financial Risk Matrix Expanded, 18 -September , 2012, Standard & Poor's Financial Services LLC. This material is reproduced with permission of Standard & Poor's Financial Services LLC.

Table 4.8 Financial risk indicative ratios for corporates

Ratings	FFO/debt in %	Debt/EBITDA (*x*)	Debt/Capital%
Minimal	Greater than 60	Less than 1.5	Less than 25
Modest	45−60	1.5−2.0	25−35
Intermediate	30−45	2−3	35−45
Significant	20−30	3−4	45−50
Aggressive	12−20	4−5	50−60
Highly leveraged	Less than 12	Greater than 5	Greater than 60

Source: Mark Puccia, Methodology: Business Risk/Financial Risk Matrix Expanded, 18 -September, 2012, Standard & Poor's Financial Services LLC. This material is reproduced with permission of Standard & Poor's Financial Services LLC.

4.1.6.2.1 Estimation of Weighted Average Cost of Capital (WACC)

In weighted average cost of capital (WACC), the cost of debt, equity, and hybrid securities are estimated on the basis of weights. Ideally, the weights should be based on the market value of these securities. The market value of equity capital is based on the price at which the share is traded. The WACC that represents the overall cost of capital is obtained by multiplying the capital structure weights by the associated costs and adding them up.

Suppose the firm's capital structure consists of equity capital, debt, and preference share capital.

$$\mathrm{WACC} = \mathrm{E/V} * \mathrm{K_e} + \mathrm{P/V} * \mathrm{K_p} + \mathrm{D/V} * \mathrm{K_d}(1 - \mathrm{T})$$

where V is the total value of the firm, E is the value of equity capital, P is the value of preference share capital, D is the value of the debt, T is the tax rate.

Table 4.9 Global Corporate Default Rates by Rating Modifier (%)

	AAA	AA +	AA	AA −	A +	A	A −	BBB +	BBB	BBB −	BB +	BB	BB −	B +	B	B −	CCC to C
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.68	0.00	0.00	2.86	7.04	2.22	2.33	7.41	21.43
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17	0.00	1.59	1.23	9.80	4.76	6.67
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40	0.00	0.00	1.64	1.49	2.15	3.51	7.69	25
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64	1.49	1.33	2.61	13.11	8.00	15.38
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.00	0.78	0.00	1.82	1.18	1.12	4.68	12.16	16.67	23.08
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	1.31	5.95	6.82	12.28
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.34	1.99	4.50	9.80	20.37
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.90	0.78	0.00	0.00	0.00	2.00	0.43	7.80	4.88	33.33
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.00	1.10	2.78	3.09	4.50	4.89	12.26	22.58	31.25
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.74	0.00	3.70	1.14	1.05	8.72	16.25	32.43	33.87
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	14.93	20.83	30.19
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.94	0.00	1.30	5.88	4.17	13.33
1994	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.00	1.84	6.58	3.13	16.67
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.00	1.56	1.12	2.77	8	7.50	28.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.56	2.37	3.74	3.85	8.00
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.35	0.00	0.00	0.00	0.41	0.72	5.30	14.58	12.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	1.06	0.67	1.06	0.72	2.60	7.56	9.46	42.86
1999	0.00	0.00	0.00	0.36	0.00	0.24	0.27	0.00	0.28	0.31	0.55	1.34	0.91	4.22	10.45	15.60	33.33
2000	0.00	0.00	0.00	0.00	0.00	0.24	0.57	0.00	0.26	0.89	0.00	0.82	2.05	5.81	10.00	11.61	35.96
2001	0.00	0.00	0.00	0.00	0.58	0.25	0.00	0.24	0.49	0.28	0.52	1.22	5.54	5.84	17.17	22.46	45.45
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.10	0.88	1.07	1.58	1.77	4.78	3.27	10.23	19.85	44.44
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.54	0.50	0.97	0.28	1.72	5.34	9.52	32.73
2004	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.67	0.52	0.47	2.35	2.84	16.18
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.37	0.00	0.51	0.79	2.64	2.96	9.09
2006	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.50	0.55	0.82	1.57	13.33
2007	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.24	0.19	0.00	0.90	15.24
2008	0.00	0.00	0.44	0.41	0.32	0.21	0.60	0.19	0.61	0.73	1.22	0.66	0.68	3.14	3.45	7.63	27.00
Avg	0.00	0.00	0.02	0.03	0.05	0.05	0.10	0.16	0.28	0.24	0.64	0.90	1.50	2.45	7.22	9.98	23.09
Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.84	0.87	2.07	6.27	7.06	22.76
Stdev	0.00	0.00	0.08	0.10	0.14	0.10	0.22	0.32	0.37	0.38	0.97	0.85	1.77	2.02	4.75	7.78	11.90
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max	0.00	0.00	0.44	0.41	0.58	0.33	0.76	1.1	1.4	1.1	3.7	3.09	7.04	8.72	17.17	32.43	45.45

Source: Diane Vazza and Devi Aurora, Default, Transition, and Recovery: 2009 Annual Global Corporate Default Study and Rating Transitions, 17−March-2010, Standard & Poor's Financial Services LLC. This material is reproduced with permission of Standard & Poor's Financial Services LLC.

Table 4.10 Interest coverage ratios and ratings high market cap firms

Interest coverage ratio	Rating	Spread (%)
More than 8.5	AAA	0.50
6.5–8.5	AA	0.65
5.5–6.5	A+	0.85
4.25–5.5	A	1.00
3–4.25	A–	1.10
2.5–3	BBB	1.60
2–2.5	BB	3.35
1.75–2	B+	3.75
1.5–1.75	B	5.00
1.25–1.5	B–	5.25
0.8–1.25	CCC	8.00
0.65–0.8	CC	10
0.2–0.65	C	12
Less than 0.2	D	14

Source: Capital IQ, Bondsonline.com.

4.1.6.2.2 Estimation of values of capital components

The market value of equity and preference share capital is based on the market price of the shares listed in the stock market and the number of outstanding shares. In other words, the market value of equity is the number of shares outstanding times the current stock price. Some analysts also use book value of equity as it is not subject to volatility and conservative in approach. Some firms issue multiple class of shares. The market values of all these shares has to be summed up and considered as equity. Other equity claims such as warrants and conversion options are also to be added to the equity value. The market value of debt is more difficult to obtain directly since firms have different types of debt. Debt in the forms of bonds outstanding are traded while nontraded debt like bank debts are stated in book value terms. Market value of traded debt are found in various sources including online.

The market value of debt that is not traded in the bond market can be estimated by converting debt into a hypothetical coupon bond similar to bonds which are traded in the bond market. In this method, the nontraded debt on the books is considered as one coupon bond with a coupon set equal to the interest expenses on the entire debt and the maturity set equal to the face value-weighted average maturity of the debt. This hypothetical coupon bond is valued at the current cost of debt. The market value of total debt is arrived at by adding the market value of traded debt and the value of nontraded debt calculated as explained above to get the total market value of debt. The debt's weighted average maturity is obtained by multiplying each component of its debt by its maturity, adding them together, and dividing by the total face value of debt.

In an alternative way, the entire book value of debt in the books is considered as one coupon bond with a coupon set equal to the interest expense on all the debt and the maturity set equal to the face value of weighted average maturity of the debt and the bond is valued at the current cost of debt for the firm.

For example, consider the current interest expense of the firm as $15,000 and a 8% current cost of debt. Suppose the total debt have two components with book value of $100,000 and $250,000.The total book value of the debt is $350,000. Suppose the maturity of first component of debt is 10 years and the maturity of second component of debt is 15 years, then the weighted average maturity period is obtained as follows

$$(100,000 * 10 + 250,000 * 15)/(350,000) = 13.57 \text{ years.}$$

Substitute the values in the bond pricing formula: $C[(1-(1/((1+R)^T)))/R]+[F/((1+R)^T)]$. In the formula, C represents the annual interest expense, R represents the current cost of debt, T represents the weighted average maturity, and F represents the total face value of debt. Substituting the values, $\$15,000[(1-(1/((1+0.08)^{13.5}))/0.08]+[\$250,000/((1+0.08)^{13.5})]$, we get the market value of the debt as $209,609.4

Alternatively, we can use the spreadsheet to find the market value of the debt. The current cost of debt of 8% is considered as the YTM, the interest rate on the debt (15,000/250,000) is assumed as the coupon rate on the bond. Using the formulae, = price(settlement date, maturity date, coupon rate, yield, redemption, frequency), the price is obtained as 84% of the par value of 250,000 which is approximately 210,000.

4.1.6.2.3 Estimations of components of debt capital

Only interest bearing liabilities are included in the debt capital. Liabilities like accounts payable and supplier credit are not interest charged liabilities. Applying after tax cost of debt to noninterest bearing liabilities will lead to misleading results regarding the true cost of debt. Hence in the estimation of cost of debt, it would be ideal to consider only interest bearing short term and long-term liabilities. Operating leases which appears as off balance sheet items in the annual report is also considered as the part of debt. The present value of the operating leases is obtained by discounting the operating lease commitments of the firm at the firm's current pretax cost of debt.

The operating income of the firm can be adjusted after considering the operating leases as a part of debt.

Adjusted operating income = Operating income + operating lease expense for the current year − depreciation on leased asset.

4.1.7 Estimation of cost of capital—industry practices

The study by Brotherson et al. (2013) provides survey results on the practices adopted by firms with respect to cost of capital estimation. The study finds that discounted cash flow is the major investment valuation technique used by firms. WACC is the dominant discount estimation method used in discounted cash flow analysis. Majority of firms calculate WACC based on market value weights. Majority of firms use marginal tax rate for the calculation of after tax cost of debt. The CAPM model is the most widely used model for estimating cost of equity. The choice of risk-free rate has a material effect on the cost of equity and cost of capital. The long-term bond yields more closely reflect the default free holding period returns available on long-term investments. The study suggests that practitioners prefer long-term treasury bond yields of 10 years or more as the popular choice of risk-free rate. Service firms like Bloomberg estimate historical beta on the basis of time interval of weekly returns over a 2-year period. The market proxy used by Bloomberg is S&P 500. Value line estimate beta based on the time interval of weekly returns over a period of 5 years. The market index proxy used by value line is NYSE Composite index.

Survey study by Fernandez et al. (2011) suggest that US market risk premium is the most widely used premium measure. One of the most widely mentioned source was Ibbotson/Morning Star. Bloomberg uses a version of DDM for the estimation of risk premium. *The annual average risk premium (difference between stock returns and long-term government bond returns) during the period 1926−2011 based on Ibbotson study (2012) was 5.7% based on arithmetic means and 3.9% based on geometric means*.

4.1.8 Estimation of WACC—Johnson & Johnson

In this section, the WACC of Johnson & Johnson is estimated. The 30-year treasury bond rate of 3.02%[7] as of November 18, 2014 is assumed to be the risk-free rate. *The average treasury bond rate during the period 2005−2013 can also be considered as the risk-free rate*. The risk premium is assumed to be 5% approximately based on various academic studies. The historical beta estimation was based on the regression of weekly returns of the stock over the market index NYSE composite during the 2-year period November 2012 to November 2014. The beta value was 0.9034. The cost of equity is estimated using CAPM.

$K_e = R_f + \text{Beta} * \text{Risk Premium}$ where K_e is the cost of equity, R_f is the risk-free rate.
The cost of equity for Johnson & Johnson in 2014 = 3.02% + 0.9034 ∗ 5 = 7.5%

The equity component consists of only equity shares. The book value of equity was $74,053 million in 2013. The book value of debt was $52,364 million, respectively. The present value of the operating lease commitments were added to arrive at the total book value of debt. The total operating lease commitments amounted to $992 million. The present value of these commitments for the period 2014−2018 and beyond were estimated using the current cost of debt (Yield on long term bond) as the discount rate of 4%. The present value of future lease commitments is arrived at 927.769 million dollars.

Total book value of debt = 52,364 + 927.769 = $53,291.769.

[7] http://www.bondsonline.com/Todays_Market/Composite_Bond_Yields_table.php.

The book value weights of equity and debt in the capital structure are 58% and 42%, respectively.

The market price per share at year end 2013 was 92.35 and number of shares 2877 million. Hence, the market capitalization was $265,690.95 million.

The yield on the long-term bond issued by Johnson and Johnson is estimated as the cost of debt. The yield on the long term bond maturing in 2043 was found to be 3.846%.[8] The coupon rate on the bond was 4.5%.[9] The price of the bond is 111% of the par value. Hence the market value of debt = 53,291.769 ∗ 1.115 = $59,420.32 million. The market value weights for equity is 82% and 18% for debt.

$$WACC = K_e\ (E/V) + K_d\ (D/V)(1 - T)$$

The cost of capital using market value weights is calculated as follows:

$$7.35\% * 0.82 + 3.8\% * 0.18(1 - 0.35) = 6.63\%.$$

The cost of capital based on book value weights is 5.42%.

The detailed calculation of the cost of capital of Johnson and Johnson is given in the resources website for Chapter 4 *Cost of Capital.xlsx*.

4.1.8.1 Estimation of cost of capital of Chevron corporation

The risk-free rate is taken as 3.45%, which was the yield on 30-year US treasury bond in 2013 as given by Federal Reserve historical database. The risk premium was taken 5.28% based on the average YTM on a 20-year US treasury bond during the time period 1993–2013. The yield on 2043 maturity bond issued by Chevron is 6.32%.[10] The cost of debt is assumed to be 6.32%.

$$\text{Cost of equity} = R_f + \text{beta} * \text{Risk Premium}$$
$$3.45\% + 0.98 * 5.28 = 8.62\%$$

The WACC based on book value weights is 7.42%, whereas based on market value weights is 8.04%. The detailed calculation is given in resources Web site *Cost of Capital.xlsx*.

[8] www.finra.org.

[9] Alternatively, the interest paid divided by the debt gives us the interest rate which can be considered as the coupon on the bond amount.

[10] http://quotes.morningstar.com/stock/cvx/s?rbtnTicker = Ticker&t = CVX&x = 11&y = 10&SC = Q&pageno = 0&TLC =

References

Amott, R.D., Ryan, R., 2001. The death of the risk premium: consequences of the 1990s. J. Portf. Manag. 27 (3), 61−74.

Arnott, R.D., Bernstein, P.L., 2002. What risk premium TB 'Normal'? Financ. Anal. J. 58 (2), 64−84.

Brotherson, W.T., Eades, K.M., Harris, R.S., Higgins, R.C., 2013. Best practices in estimating the cost of capital: an update. J. Appl. Finance. (1), 15−33.

Campbell, J.Y., Shilier, R.J., 2001. Valuation Ratios and the Long-Run Stock Market Outlook: An Update. National Bureau of European Research, Cambridge, MA, NBER Working Paper No. 8221.

Cooper, I., 1996. Arithmetic versus geometric mean estimators: setting discount rates for capital budgeting. Eur. Financ. Manage. 2 (2), 157−167.

Damodaran, A., 2006. Estimating discount rates. Discounted Cash Flow Valuation, Damodaran on Valuation, second ed. Wiley Finance, 72 (Chapter 2).

Damodaran, A., 2012. Investment valuation. Riskless Rates and Risk Premium, third ed. Wiley Finance, 162.

Damodaran, A., 2012. Investment Valuation, Tools and Techniques for Determining the Value of Any Asset. third ed. John Wiley and Sons, Inc, Chapter 4, 47−65.

Elroy, D., Marsh, P., Staunton, M., 2002. Triumph of the Optimists 101 Years of Global Investment Returns. Princeton University Press, pp. 176−196.

Elroy, D., Marsh, P., Staunton, M., 2003. Global evidence on the equity premium. J. Appl. Corp. Financ. 27−38.

Elroy, D., Marsh, P., Staunton, M., 2011. Equity Premia Around the World. London Business School, <https://www.fairr.de/docs/dimson-marsh-staunton-2011.pdf>, 1−19.

Fama, E.F., French, K.R., 2002. The equity premium. J. Finance. LVII (2), 637−659.

Fernandez, P., Aguirreamalloa, J., Corres, L., 2011. US Market Risk Premium Used in 2011 by Professors, Analysts and Companies: A Survey with 5,731 Answers,. IESE Business School Working Paper, 1−17.

Fernando, D., Carlo, R., 2013. The Equity Risk Premium: A Consensus of Models, <http://ftp.ny.frb.org/research/economists/duarte/Duarte_Rosa_EquityRiskPremium.pdf>, 1–22.

Fabio Fornari, 2002. "The Size of the Equity Premium," Economic Working paper 447, Bank of Italy, Economic Research and International Relations Area.

Fornari, F., 2002 The Size of the Equity Premium. Economic Working paper 447, Bank of Italy, Economic Research and International Relations Area.

Goyal, A., Welch, I., 2001. Predicting the Equity Premium with Dividend Ratios. Yale School of Management and UCLA, Working Paper.

Goyal, A., Welch, I., 2008. A comprehensive look at the empirical performance of equity premium prediction. Rev. Financ. Stud. 21 (4), 1455−1508.

Grabowski, R.J., 2011. Developing the cost of equity capital: risk free rate and ERP during periods of "Flight to quality", <www.duffandphelps.com/sitecollectiondocuments/articles/Article_Grabowski_Risk_Free_Rate_and_ERP_During_Flight_to_Quality_01_29_11.pdf>, 1−27.

Graham, J.R., Harvey, C.R., 2001. Expectations of Equity Risk Premia, Volatility and Asymmetry from a Corporate Finance Perspective.. Fuqua School of Business, Duke University, Working Paper.

Harris, R., Marston, F.C., 1999. The Market Risk Premium: Exceptional Estimates Using Analysts Forecast. Darden Business School, Working Paper N0-99-08.

Ibbotson, R.G., Chen, P., 2003. Long run stock returns : participating in the real economy. Financ. Anal. J. 59 (1), 88–98.

Kozhan, R., Anthony, N., Schneider, P., 2013. The skew risk premium in the equity index market. Rev. Financ. Stud. 26 (9), 2174–2203.

Mayfield, S., 2004. Estimating the market risk premium. J. Financ. Econ. 73, 465–496.

Shannon, P., Graboswski Roger, J., 2010. Chapter 7, 9, Cost of Capital: Applications and Examples. fourth ed. John Wiley & Sons.

Robert, A., 2001. Historical Results, Equity Risk Premium Forum. CFA Institute (AIMR), Nov 08, 27.

Siegel, J.J., 1999. The shrinking equity risk premium. J. Portf. Manage. 26 (1), 10–17.

Welch, I., 2000. Views of financial economists on the equity premium and other issues. J. Bus. 73 (4), 501–537.

Zenner, M., Hill, S., Clark, J., Mago, N., 2008. The Most Important Number in Finance, The Quest for the Market Risk Premium. Capital Structure Advisory & Solutions JP Morgan, pp. 1–11.

Annex 543

E. Erragragui, "Do creditors price firms' Environmental, Social and Governance risks?", *Research in International Business and Finance,* 2018, pp. 197-207

Research in International Business and Finance 45 (2018) 197–207

Contents lists available at ScienceDirect

Research in International Business and Finance

journal homepage: www.elsevier.com/locate/ribaf

Full length Article

Do creditors price firms' environmental, social and governance risks?

Elias Erragragui[a,b]

[a] Kedge Business School, Rue Antoine Bourdelle, Domaine de Luminy BP 921, 13 288 Marseille Cedex 9, France
[b] CRIISEA, Université de Picardie Jules Verne, 10 Placette Lafleur BP 2716, 80 027 Amiens Cedex 1, France

ARTICLE INFO

Keywords:
Corporate social performance
Environmental performance
Governance disclosure
Cost of debt
U.S firms

ABSTRACT

The relationship between Corporate Social Performance (CSP) and firm value has received a growing attention in recent academic literature. Despite the rich contributions it has led to, few studies attempted to investigate the link between CSP and firms' credit risk. This research fills this gap and empirically examines the relationship through which CSP impacts firms' cost of debt. Using KLD social ratings, the study isolate specific constituents of firms' CSP found to have operational implications in creditors' risk perception. Observing a panel of 214 U.S firms from December 2000 to December 2011, the results show that only few constituents of CSP actually matters in creditor's perception of firms' risks. Our prime results show that environmental concerns increase firms' cost of debt while governance concerns have no impact on it. Secondarily, the results also confirm that environmental and governance strengths reduce firms' cost of debt as demonstrated in prior works. Our findings thus reveal a "governance paradox" whereby governance strengths and governance concerns are not considered with the same importance by creditors.

1. Introduction

The development of Corporate Social Responsibility (CSR) strategies among multinational companies is becoming prominent (Hayward et al., 2013). The latest UN Global Compact study on sustainability surveyed more than one thousand CEOs from all over the world. It revealed that 93% of them consider CSR as an "important" or "very important" element in the future success of their organizations. It is therefore not surprising that so much attention has been given by researchers to capture the economic and social outcome produced by the implementation of CSR policies. For instance, the development of Environmental disclosure schemes is becoming more and more frequent among listed firms. The disclosure of environmental information include pollution reporting such as the U.S. Toxics Release Inventory and U.S. Environmental Protection Agency's Greenhouse Gas Reporting Program (GHGRP); or external ratings by experts and analysts such as KLD, Greenpeace's scorecard. Despite their important dissemination, there is no consensus about the impacts of environmental disclosure programs on businesses, and more generally on society (Fung et al., 2007). Similarly, corporate governance disclosure programs were proliferating rapidly since the Sarbanes-Oxley Act adopted by U.S. congress in 2002 just after the financial scandals that originated Enron and Worldcom's collapses in 2000. This proliferation was pushed by the development of international guidelines such as the Organization for Economic Co-operation and Development (OECD) Principles of Corporate Governance—published in 1999 and revised in 2004 or the report published in 2009 by the International Finance Corporation and the UN Global Compact linking the environmental, social and governance responsibilities of a company to its financial performance and long-term sustainability. Despite the democratization of corporate governance standards across the world, the literature exploring its effects on firms' behavior provide various and mitigated conclusions.

E-mail addresses: elias.erragragui@kedgebs.com, erragragui_elias@yahoo.fr.

http://dx.doi.org/10.1016/j.ribaf.2017.07.151
Received 26 September 2015; Received in revised form 30 October 2016; Accepted 6 July 2017
Available online 09 July 2017

Among the different risks linked to firms' activities, credit risk has been defined as the risk of an economic loss from the failure of a counterpart to fulfill its contractual obligations (Jorion, 2007), which is affected by various firms characteristics such as leverage, earnings, collateral, reputation and management competency (Altman and Hotchkiss, 2006). The objective of this study is to examine empirically whether the CSR initiatives that potentially impact firms' operational and financial risks are priced by creditors. The study is of interest for at least two reasons. First, the number of studies examining the link between firms' CSP and their Cost of Debt (CoD) is very limited as compared to the works investigating the CSP-cost of equity puzzle. Second, several authors have pointed out the limits of composite measures of CSP to fully capture the channel of causality linking its constituents with firms' operations (Mattingly, 2017). This study offers then to isolate the different sub-components of CSP while investigating the CSP-CoD relationship.

Another interest of investigating creditors' appreciation of CSR policies can be found in the importance of corporate debt market in current financial system. According to some estimation, global equity outstanding represented $50 trillion by 2012 whereas corporate debt market exceeded $86 trillion.[1] The importance of debt market in corporate financing invites to deeper investigations of the impact of CSR initiatives on creditors' perception of firm risk.

In the next section, we review existing literature on the relationship between corporate social performance and firms' financial performance and its cost of debt respectively. The following section presents our methodological setting and the specification of our models. The penultimate section reports the results of the empirical tests before the final summary and conclusion.

2. Literature review and hypothesis development

This section first reviews the relevant literature and then explains development of the hypotheses being tested. The literature review addresses the CSP-Financial Performance (FP) debate, and then the CSP- Cost of Debt studies with an emphasis on the link between corporate governance, environmental performance and the CoD.

2.1. The CSP-financial performance debate

CSR and its sister concepts – Corporate Social Performance, corporate social responsiveness, corporate citizenship – have been present in management scholarship for about 45 years (Wood, 2010). Managerial theorists highlighted the necessity not to separate the economic objectives of the firm and the objectives of CSR initiatives (Porter and Kramer, 2006). Thus, most of the research has been on attempting to investigate a statistical relationship between CSP and financial performance so as to legitimize or disqualify the normative calls for managers to promote CSR strategies. Nonetheless, the plethoric empirical studies examining the effect of CSR strategies on firms' performance have left balanced conclusions. Indeed, despite the important number of studies investigating the CSP-Financial Performance (FP) relationship, several authors highlight the failures surrounding their theoretical foundations. Rowley and Berman (2000) for instance criticized the vain attempts to generate a "universal theory of CSP-FP" and argue that the CSP concept is not in itself a "viable construct" and should rather be considered in very specific operational settings. They point out the necessity to narrow defined organizational context by distinguishing the different variables encapsulated in the generic "CSP" terminology.

So far, the majority of studies dealing with specific subcomponents of CSP suggest that specific operational measures of CSP, such as corporate governance disclosure, pro-environmental waste treatment or employees' training programs, are positively related with firm financial performance (see Frooman, 1997; Margolis et al., 2007; Orlitzky et al., 2003; Wood and Jones, 1995). While Barnett and Salomon (2011) observed that most of the studies that use Kinder, Lydenberg, Domini & Co., Inc. (KLD)[2] data measure the performance using composite scores, a recent review conducted by Mattingly (2017), throughout 100 empirical studies using KLD data, insists that decomposing CSP into its constituent latent components yields understanding and exemplifies the benefits of progressively sophisticated analytical methods.

Most of the empirical studies are grounded by theories suggesting that good managerial practices and greater attention to key stakeholders decrease firms' costs (Moskowitz, 1972; Turban and Greening, 1997). Some authors for instance highlights that some aspects of CSR contribute to foster innovation and competitive advantage and thus increase productivity (Aragon-Correa, 1998; Russo and Fouts, 1997; Shrivastava, 1995). For others, an efficient environmental and resources management can reduce firm operational risks (Orlitzky and Benjamin, 2001). Thus, an increase in the firm's performance can be the result of both an increase in its revenues from enhanced productivity and a reduction of its operational costs due to improved governance and more efficient resource management.

In the plethora of literature addressing the effect of CSP on firms' value, we found a large proportion focusing on the cost of capital as proxy for financial performance (see for e.g. Cellier and Chollet, 2016; El Ghoul et al., 2011; Galema et al., 2008; Hong and Kacperczyk, 2009; Kempf and Osthoff, 2007; Sharfman and Fernando, 2008). The important number of studies examining the CSP-Cost of equity relationship contrasts with the very limited number of works investigating the CSP-Cost of debt relationship.

[1] http://www.mckinsey.com/insights/global_capital_markets/financial_globalization.

[2] Although KLD has changed its denomination for MSCI ESG Research, we have decided, for convenience, to keep this denomination due to its extensive use in the literature.

2.2. The CSP-cost of debt relationship

The very limited number of CSP-Cost of debt related studies is not surprising. Conventionally, equity capital market is perceived as more efficient for pricing firms' social performance than credit market. Usually, researchers argue that credit intermediation lack transparency concerning borrower's social commitment and more importantly do not possess the same analytical abilities than investment analysts have. Theory suggests that stockholders main interest rest upon firm's future profitability, which is found to be affected by good management incentives (Waddock and Graves, 1997). On the other side, creditors' preference goes only for firm's repayment capacity and solvency, which seems to be less directly affected by managerial competency. However, some authors argue that a good and proactive management can be very important in the debt pricing due particularly to the agency conflict arising between shareholders and debt-holders (Ashbaugh-Skaife et al., 2006). When raising capital, firms have to select between the optimal proportion of equity and debt according to how stockholders or creditors appreciate firm's profitability or firm's riskiness respectively. The works of Merton (1973) showed that the payoffs accruing from a corporate bond is asymmetric and look like that of a put position. This observation expresses the fact that while the potential benefit of the borrower remains stable at the level of the interest rate, the potential losses can amount to the entirety of the loan which makes the imperative to reduce agency costs by emphasizing on management aspects. The author adds that such imperative is even more important for debt-holders than for equity-holders whose payoff is more symmetrically aligned with firm's risk profile.

Some researchers thus consider the possibility that private debt markets integrate firms' social performance as determinants of its credit risk profile. It is argued that private debt market, that equals at least two to three times the amount of public debt market, are more "informationally efficient" as they manage to reflect the probability of default more quickly (Altman et al., 2010). The literature related to *agency cost theory* (Jensen and Meckling, 1976) and debtors' function in firms' management has long emphasized on the role of banks as delegated monitors which benefit is to reduce monitoring costs faced by shareholders (Diamond, 1984). Indeed, banks have access to specific information about the firm that is not always available to outsiders. Our prime interest then focuses on the key role of private creditors as "quasi-insiders" of the firm (Goss and Roberts, 2011) to investigate whether these creditors discriminate between the different levels of CSP.

Scholtens and Zhou (2008) found as well that social harm is positively associated with financial risk. Barnea and Rubin (2010) showed that debt leverage, usually associated with financial risk, was negatively related to CSP. As firm risk is often measured by the intensity of its financial performance fluctuations over time (Donaldson, 1998), if good CSP can reduce firm operational risk exposure, it may potentially lower cash flow volatility, risk and consequently the cost of debt (Orlitzky and Benjamin, 2001). Sun and Cui (2014) demonstrated that an effective risk management and good CSR standards are associated with lower costs of debt. Given the small number and heterogeneity of CSP-Cost of debt (CoD)-related studies, the question of the sign and intensity of the CSP-Cost of debt relationship remains open.

2.2.1. Corporate governance and CoD

To build our testable hypotheses, we first look at the conclusions extracted from existing literature. It is globally argued that a firm with good corporate governance practices will be perceived as more transparent and trustworthy by creditors, and therefore will be considered with a low default risk profile. The works conducted by Sengupta (1998), Bhojraj and Sengupta (2003) and Anderson et al. (2004) on bonds pricing provide evidence that firms with high governance standards and high disclosure quality enjoy a lower interest rate. Klock et al. (2005) suggest that improved management rights, such as antitakeover governance provisions, although not beneficial to stockholders, are viewed favorably in the bond market. More recently, Andrade et al. (2014) investigated the impact of the Sarbanes–Oxley (SOX) Act on the cost of debt through its effect on the reliability of financial reporting. Using Credit Default Swap (CDS) spreads and a structural CDS pricing model, they show that corporate opacity and the cost of debt decrease significantly after SOX. The effect of corporate governance on the CoD have also been investigated by Aldamen and Duncan (2012) who examined Australian corporate bonds' market and show that increased corporate governance lowers cost of debt. Aman and Nguyen (2013) found that good governance is associated with higher credit ratings suggesting that active monitoring (by large shareholders) and lower information asymmetry (through better disclosures) reduce agency conflicts and mitigate the risk to debtholders.

Despite the affirmation of Altman and Hotchkiss (2006) that "the most pervasive reason for a firm's distress and possible failure is some type of managerial incompetence", little attention has been paid to the impact of governance controversies on firms' cost of debt. According to the authors, although firms fail for multiple reasons, "management inadequacies are usually at the core of the problems". Bad governance practices can affect firm's trustworthiness and risk perception by external observers (Bedard and Johnstone, 2004; Nooteboom et al., 1997). Empirically, several authors observed that distressed firms' governance characteristics significantly affect their probability of bankruptcy (Fich and Slezak, 2008; Goss, 2009). This observation led us to isolate negative firms' governance indicators from positive ones to narrow our CSP-CoD relationship investigation instead of combining them into a single indicator of corporate governance. Furthermore, in line with the observation of Altman et al. (2010) that "syndicated loan markets are more informationally efficient compared to bond markets" due to their ability to reflect the probability of default more quickly, and in opposition with prior findings who mainly concerns bond markets, we decide to enlarge our investigation to all type of debts reported in firms' book.

KLD's scoring has the advantage of isolating governance positive indicators (strengths) from negative ones (concerns) while covering a large aspect of management misconducts such as: firm's executive compensation controversies, bribery, accounting irregularities, etc. The study of Kang (2015) on KLD's corporate governance ratings effectiveness lend support for empirical studies relying on the KLD ratings to operationalize corporate social performance. To our knowledge the link between governance concerns and firms' cost of debt has not being yet explored. Based on prior observations suggesting that firms with high good governance standards enjoy a lower cost of debt (Sengupta, 1998), we intuitively propose that:

H1. There is a significant positive relationship between firms' governance concerns and firms' cost of debt.

2.2.2. Environmental performance and CoD

Beside the impact of governance concerns on firms' cost of debt, we decide also to consider environmental performance which has been extensively reported to impact the financing costs of a firm. Thompson and Cowton (2004) documented the extent to which UK banks incorporate environmental considerations into their corporate lending decisions arguing that "even if banks are not directly concerned about the environment, they have an incentive to understand the environmental implications of their lending decisions".

Credit risk is affected by environmental risk in various ways – direct, indirect or reputational (Mengze and Wei, 2015). A creditor may suffer direct risk due to incurring direct liability for cleaning up pollution caused by an insolvent borrower. He may suffer indirect risk if the borrower is liable for paying financial penalties impairing its profitability and cash flows due to the harms caused by its operations on the environment A creditor reputation can also be affected he is found to finance projects or borrowers known to be environmentally irresponsible (Coulson and Monks, 1999). Environmental Credit Risk Management (ECRM) studies witnessed a growing attention these last years. Authors advocate that environmental risks could significantly affect credit risk (Caouette et al., 2011; Weber et al., 2008). Scholz et al. (1995) found that in about 10% of all credit losses in German banks environmental risks were involved. In a follow up study, For Weber (2012) the credit losses attributable to environmental issues are caused by a reduction in securities from contamination and the costs linked to environmental disasters management imposed by a regulators. Weber et al. (2010) shown that the rate of correct credit default predictions improved by approximately 7.7% when sustainability criteria were added to conventional credit risk indicators. These findings indicate that creditors have tangible reasons to place increasing importance on environmental credit risk management in their corporate lending operations (Thompson and Cowton, 2004; Weber, 2012). Mengze and Wei (2015) observe that the development of ECRM, which implies the integration of standardized risk assessment procedures into credit rating process, is gaining importance in the risk management of banks.

Two issues appear important to use in our review of the literature. First, so far existing literature on the relationship between environmental performance and firms' financing costs emphasized heavily on the positive effect of firms' pro-environmental management policies while neglecting the adverse effect link to the reporting of environmental concerns (see for e.g. Hart and Ahuja, 1996; Khanna and Damon, 1999; Kim, 2013; Porter and Van der Linde, 1995; Sharfman and Fernando, 2008). Second, as noticed by Escrig-Olmedo et al. (2017), one of the main issue of current studies remains the excessive use of composite measures of corporate environmental performance that fail to be both "comprehensive and consistent with sustainable development both for society and companies". The authors explain that due to the multidimensional character of the sustainability concept, the question of the qualitative nature of indicators and the complexity of developing a synthetic index must be considered in the evaluation process. For many researchers the corporate environmental performance information remains "extremely complex" (Chatterji et al., 2009). Thus, similarly to our first hypothesis development, we decide to distinguish between environmental strengths and environmental concerns in our investigation of the link between corporate environmental performance and firms' CoD. Indeed, it appears important for us to isolate KLD's positive indicators of proactive pro-environmental policies, such as the use of recycling facilities, from negative indicators of environmental impact, such as the release of toxic waste as they implies two different treatment by creditors. Schneider (2011), for instance, who focused exclusively on negative environmental impact when investigating the pulp and paper and chemical industries, managed to demonstrate that a high level of toxic release presents a significant downside risk in future cleanup and compliance costs and that these costs can be large enough to threaten the ability of polluting firms to meet their fixed payments to creditors. The author explained that the threat of future new environmental regulation introduces uncertainty in the estimation of future cash flows and subsequently firms' capacity to meet their debt obligations.

KLD ratings report various significant concerns linked to toxic chemical substances treatment and not only the level of toxic waste release. For instance, while reporting the excessive liabilities for hazardous waste incurred by irresponsible firms, they also report whether the company is among the top manufacturers of ozone depleting chemicals such as HCFCs, methyl chloroform, methylene chloride, or bromines, or whether they produce pesticides, chemical fertilizers or derivative fuel products such as coal or oil. KLD also reports the presence of fines or civil penalties linked to the violations of environmental regulations. Overall, KLD's environmental concerns indicators encompass at least six distinct items linked to toxic components production, disposal or release. Assuming that the operational risks originated from the treatment of toxic chemical substances is well reported by KLD ratings and that these operational risks may increase default risk, we propose that:

H2. There is a significant positive relationship between firms' environmental concerns and firms' cost of debt

3. Research method

3.1. Sample selection and dataset

We use the KLD social performance dataset as indicators of corporate social performance. Graves and Waddock (1994) promoted KLD dataset as the best single source of social and environmental performance data. Chatterji et al. (2009) found substantial correlation between KLD's environment-related data and other well-known measures of environmental performance, confirming KLD data's correspondence to the theoretical CSP construct. The latest investigation of Delmas and Blass (2010) also concluded that KLD environmental strengths and concerns were highly correlated with other objective measures of environmental performance and with a content analysis of firms' sustainability reports.

Table 1
Descriptive sectors.

Sectors	Number	Mean CoD
Manufacturing	104	5.89%
Construction	1	12.65%
Finance, Insurance and Real estate	27	9.46%
Mining	12	6.74%
Retail Trade	19	6.43%
Services	8	3.68%
Transportation and Public Utilities	39	6.22%
Wholesale trade	4	5.39%
Total	214	

Based on SIC codes. The mean CoD represents the mean value of the financial expenses to debt ratio calculated for each firm over the period 2000–2011.

KLD provides a database from 1991, which includes the ratings of stocks on an annual basis. The database is free of survivorship bias. At its inception date, KLD covered all stocks from the S & P 500 and the DS 400 (a total of around 662 stocks). Accordingly, we form our initial data set based on the 662 firms that constituted KLD's coverage by 2000. After retrieving and consolidating the financial data, we obtained a final panel of 214 U.S firms.[3] The period of observation goes from December 2000 to December 2011. Table 1 presents the distribution of firms by sector. The manufacturing sector, i.e. firms engaged in the mechanical or chemical transformation of materials or substances into new products, is over-represented in the sample (49%). This sector if followed by the transportation and public utilities (18.2%) and the financials (12.6%). The mean of the cost of debt calculated at a sector level indicates some disparities with, for the highest level, the financials (9.46%), and the services at the lowest (3.68%).[4] It should be noted that firms from the financial sector restructure their debt more frequently than other sectors. This can explain why their cost of debt is higher in percentage of their debt-holdings.

3.2. CSP measurement

The independent variables used in this study include the seven areas of stakeholder management on which KLD rates company's CSR initiatives: community, diversity, employee relations, environment, human rights, product and corporate governance. For each theme KLD evaluates multiple sub-criteria. The sub-criteria are divided into "strengths" and "concerns". For example, a cash profit sharing program for the workforce would be a strength and poor safety standards for the workforce would be a concern. The presence of a strength or a concern is indicated by 1, their missing is indicated by 0. KLD does not aggregate the scores of the sub-criteria to obtain an overall score for each theme. As we previously suggested, many authors criticized the use of composite measure of CSP for its lack of empirical validity (Johnson and Greening, 1999; Mattingly and Berman, 2006; Mitnick, 2000; Szwajkowski and Figlewicz, 1997) underlining the complexity of the construct's theorized multi-dimensionality (Carroll, 1979, 1999). Alternative approaches adopt multivariate measures supposed to correspond to distinct latent patterns of social activity. One of the two alternative approaches that dominate the literature distinguishes between positive and negative aspects by summing KLD's strength and concern items separately. Authors advocating this approach argue that positive and negative social action are, both conceptually and empirically, distinct patterns of corporate activity (Mattingly and Berman, 2006; Scholtens and Zhou, 2008; Van der Laan et al., 2008). They indicate that strength and concern variables lack convergent validity (Sharfman, 1996). Scholtens and Zhou (2008) for instance insist that, although social harm is positively associated with financial risk, social benefit does not impact directly on financial risk, refining an earlier finding that CSP was associated with reduced financial risk (McGuire et al., 1988). Additionally, we argue that separating positive from negative ratings allows us to counter the "greenwashing" effect whereas socially controversial firms disguise their concerns and legitimize themselves by declaring the adoption of CSR policies, generally reported as positive indicators of CSP by analysts despite their lack of operational materiality (Dawkins and Fraas, 2013; Laufer, 2003). In our study, and for comparative purpose, we decide to investigate both the relationship between composite measure of CSP and firms' CoD and between its specific components linked to governance and environmental performance. To do so we use two approaches: a baseline approach in which we simply separate the concerns from the strengths in the form of two composite CSP scores and a domain-based approach in which we isolate the strengths and concerns obtained for each of the seven KLD's domains. We then control for the presence of cross-sectional correlations between the ratings. The results are shown in Table 2. The correlations are generally not high and confirm that the seven domains rated by KLD can be treated as different sub-components of CSP; the correlation between the human rights strengths and the corporate governance strengths is the highest with 0.39.

3.3. CoD measurement

We decide not to rely on credit ratings as proxy for the cost of debt as it mainly concerns credit risk pricing in bonds market. We decide rather to use the accounting cost of debt figure to account for both traditional bank loans and bonds. Also, we find that

[3] The financial and accounting data were retrieved from Bloomberg database.
[4] We exclude construction's sector from the analysis since it represents only one firm.

Table 2
Correlations of KLD's ratings per domains.

	KLD's criteria						
	CG_STR	COM_STR	DIV_STR	EMP_STR	ENV_STR	HUM_STR	PRO_STR
CG_STR	1						
COM_STR	0.16***	1					
DIV_STR	0.08***	0.19***	1				
EMP_STR	0.23***	0.18***	0.17***	1			
ENV_STR	0.23***	0.14***	0.17***	0.12***	1		
HUM_STR	0.39***	0.12***	0.01	0.20***	0.09***	1	
PRO_STR	0.13***	0	−0.10***	0.11***	0.20***	0.11***	1
	KLD's criteria						
	CG_CON	COM_CON	DIV_CON	EMP_CON	ENV_CON	HUM_CON	PRO_CON
CG_CON	1						
COM_CON	-0.01	1					
DIV_CON	0.03	0.08***	1				
EMP_CON	0.14***	0.11***	−0.01	1			
ENV_CON	0.14***	0.18***	0.07***	0.09***	1		
HUM_CON	0.28***	0.18***	0.20***	0.05**	0.11***	1	
PRO_CON	0.19***	0.15***	0.13***	0.10***	0.25***	0.25***	1

***, **, * denote a significant correlation at the 0.01, 0.05 and 0.10 levels, respectively.

Orlitzky et al.'s meta-analytic study (2003) revealed that CSR is more correlated with accounting-based measures than with market-based indicators. Given that some firms' accounting variables are highly skewed, we conduct a natural logarithmic transformation on certain of them. Accordingly, we identify our dependant variable, the cost of debt (LOG_CoD), by the logarithm of the accounting ratio between financial expenses and total amount of financial debt.

3.4. Control variables

We include a set of firm-specific control variables based on previous studies. Theory states that the risk associated with excessive leverage will likely increase the firm's cost of capital (Baxter, 1967). A high degree of leverage is expected to increase the probability of bankruptcy. We identify the variable LOG_LEVERAGE as the ratio of financial debt over equity capital. Size is an intensively used variable in studies dealing with debt policy explanatory factors. Gruber and Warner (1977) and Ang et al. (1982) have shown that bankruptcy costs are much lower for big firms. As stated in the *trade-off theory*; firms decide how much debt/equity financing they require by weighting the costs and benefits of such decision. Large sized firms differ from small firms in terms of credit ratings, constant cash flow, and lower risk of bankruptcy. They are capable of decreasing transaction costs of issuing long-term debt at a favorable low rate of interest (Agrawal and Nagarajan, 1990; Rajan and Zingales, 1996; Titman and Wessels, 1988). A negative relationship is therefore predicted between firms' size and their cost of debt. We define LOG_SIZE as the natural logarithm of total assets.

Creditors consider the economic growth as a good indicator of lower default risk and thus will be ready to charge lower costs. Following the agency theory (see Jensen and Meckling, 1976), agency costs are expected to be higher for firms with lower growth perspective (i.e. high Book-to-Market ratios), since these firms are more likely to waste free cash flows. We introduce the control variable, LOG_BTM,[5] predicting a firm's economic growth and measured as the logarithm transformation of Book-to-Market (BtM) ratio. The profitability of a firm is perceived as a positive determinant of firms' repayment capacity and is therefore negatively associated with its CoD. We use the return on invested capital (ROIC) to measure a company's efficiency at allocating the capital under its control to profitable investments. It is given by the ratio between net income minus dividends and total capital. The variable INTEREST identifies interest coverage and is measured as the ratio between EBIT and financial expenses. This variable is used as a proxy for firm's solvency and is expected to be negatively correlated to the CoD.

3.5. Models' specification

The impact of corporate social performance on firm's cost of debt is examined using the following model:

$$CoD\ i,t = f\ (CSP\ i,t\text{-}1,\ Control\ Variables\ i,t) \tag{1}$$

[5] The use of logarithmic transformation in a regression model is justified from an econometric viewpoint by the presence of non-linear relationship between the independent and dependent variables. Using the logarithm of one or more variables instead of the un-logged form makes the effective relationship non-linear, while still preserving the linear model. In our case the independent variables concerned by the logarithmic transformation (Leverage, Size and BTM) are presented by the literature as having a non-linear relationship with our dependent variable (the CoD) as they proxy for default risk which is subject to threshold effects.

where:

CoD i,t: Cost of debt issued in year t.

CSP t-1: Corporate social performance announced at the end of the year t-1.

Since KLD scorings are publicly released at the end of the year, CSP (STR and CON) variables are measured at time t-1 to allow for the public release.[6]

We carried out a set of tests (F-test and Chi-square test) to justify the use of a panel data methodology. We have also decided to consider controlling for time and firm fixed effects after carrying out a Hausman test. The result confirms the correlation between individual-specific errors and our set of control variables and justifies the use of fixed-effects estimation model as compared to random-effects model.

One of the main issues to tackle in the specification of our model concerns endogeneity bias. Indeed, some omitted variables may affect both CSP indicators and our dependent variables at the same time, resulting in a spurious correlation. For example, small firms with limited collateral may not be able to beneficiate from low-cost debt financing and at the same time cannot afford to invest intensively in CSR practices. Nikolaev and Van Lent (2005) show how including a set of variables, which theory suggests to be related with both cost-of-debt capital and disclosure and using fixed effects estimation in a panel data-set, should reduce the endogeneity bias while producing consistent results.

We decided to rely on a log-linear (or semi-log) specification to ease the literal interpretation of the estimated coefficient. Accordingly, we model the relation between the cost of debt of a firm i (LOG_CoD) and its total strengths and concerns' scores expressed by the variables STR and CON, and the corresponding sub-total for each of the *j* sub-domains[7] expressed by SUB_STR and SUB_CON. Thus, we run the following regressions over the period from December 2000 to December 2011:

$$LOG\_CoD\ \ it = \alpha + \beta 0LOG\_LEVERAGE\ \ it + \beta 1LOG\_SIZE\ \ it + \beta 2LOG\_BTM\ \ it + \beta 3INTEREST\ \ it + \beta 4ROIC\ \ it + \beta 5STR\ \ it\text{-}1 + \beta 6CON\ it\text{-}1 + \varepsilon \quad (1a)$$

$$LOG\_CoD\ it = \alpha + \beta 0LOG\_LEVERAGE\ it + \beta 1LOG\_SIZE\ it + \beta 2LOG\_BTM\ it + \beta 3INTEREST\ it + \beta 4ROIC\ it + \beta 5SUB\ j\_STR\ it\text{-}1 + \beta 6SUB\ j\_CON\ it\text{-}1 + \varepsilon \quad (1b)$$

The results are discussed in the following section.

4. Results

Table 3 presents the descriptive statistics of the dependent and control variables and Table 4 shows its correlations matrix. Table 5 reports the results of the estimation of models (1a) and (1b), where LOG_CoD is regressed on the control variables and the CSP variables distinctively. Consistent with previous findings (Goss and Roberts, 2011; Sharfman and Fernando, 2008), the results displays significant negative loadings for debt leverage, firm size and interest coverage variables regardless of the type of CSP measurement approach and domains. More surprisingly the results report non-significant loadings for BtM ratio. The absence of significant relationship between BtM ratio and the CoD can be attributed to opposing effects. Form one side, a negative effect of BtM ratio can be explained by the positive appreciation by creditors of growth perspectives. From another side, a positive effect can arise from the fact that banks apply high interest rates to young firms with risky growth opportunities.

Our prime result shows the absence of relationship between a firm's CoD and its CSP when measured at a composite level. It thus confirms the initial argument referring to the lack empirical validity of CSP construct (Johnson and Greening, 1999; Mattingly and Berman, 2006; Mitnick, 2000; Szwajkowski and Figlewicz, 1997). This conclusion appears to hold even after discriminating between the positive indicators (strengths) and the negative ones (concerns) in the measurement of CSP, suggesting that the multi-dimensionality of CSP construct originated from the seven areas of stakeholder management on which KLD rates company's CSR initiatives hinder the relationships that potentially exist at the operating level. Indeed, in line with Mattingly's (2017) observation our second set of results confirms that firms' CoD is affected by some sub-constituents of CSP. First, we report a significant negative loading for the variable identifying good governance (-0.006 at 10% level). This result shows that an increase of one unit in KLD's good governance scoring (CG_STR) will lead to an expected decrease of 0,6% in the cost of debt measured as the accounting ratio between financial expenses and total amount of financial debt. This result, albeit marginal in term impact, confirms previous findings[8] suggesting that the quality of CSR reporting is negatively associated with firms' CoD (Nikolaev and Van Lent, 2005; Sengupta, 1998). They imply that a policy of timely and detailed CSR disclosures may reduce lenders' and underwriters' perception of default risk for the disclosing firm. Since debt financing is an important source of external financing for publicly traded firms, the results have important implications on our understanding of the motives and consequences of CSR disclosures. Contrary to our prime prediction, our results report no significant loading for governance controversies indicator. We argue that the potential adverse effect of

[6] Other authors adopted the same approach. See for example Schneider (2011) or Sengupta (1998).

[7] Using a reference year t for our dependent variable, we estimated our models using CSP data from $t-2$ to $t-1$ to see if any other lag in this data was appropriate. We obtained meaningful results only with the data from t-1 (a one-year lag). So we used those values in our analysis.

[8] The interpretation of this result should consider that KLD's governance "strengths" indicator only focus on firms' sustainability reporting practices and does not address firms' global reporting and governance good practices such as independence of board members or audit committee structure. As such, it cannot be used as proxy for good corporate governance practices.

Table 3
Descriptive statistics (N = 214).

Variable	Obs	Mean	Std. Dev.	Min	Max
LOG_CoD	1843	0.74	0.2	−0.65	1.41
LOG_LEVERAGE	1847	1.76	0.42	−0.92	2.87
LOG_SIZE	1852	4.13	0.53	2.4	5.9
LOG_BTM	1852	-0.45	0.26	−1.42	0.62
INTEREST_COV	1843	14.84	26.73	−0.11	581.71
ROIC	1852	11.86	12.69	-413.44	137.27

Table 4
Pearson correlations matrix for control variables used for regressions.

Variables	LOG_CoD	LOG_LEVERAGE	LOG_SIZE	ROIC	LOG_BTM	INTEREST_COV
LOG_CoD	1					
LOG_LEVERAGE	−0.20***	1				
LOG_SIZE	−0.25***	0.13***	1			
ROIC	0.03	-0.16***	−0.02	1		
LOG_BTM	0.17***	0	0.05**	−0.37***	1	
INTEREST_COV	−0.17***	-0.53***	0.03	0.24***	−0.28***	1

***, **, * denote a significant correlation at the 0.01, 0.05 and 0.10 levels, respectively.

Table 5
Results of the regression analysis; dependent variable: CoD.

Independent variables	Model 1a: Composite CSP	Model 1b: Disaggregated measure of CSP						
LOG_LEVERAGE	−0.114***	−0.114***	−0.113***	−0.113***	−0.115***	−0.116***	−0.114***	−0.145***
LOG_SIZE	−0.111***	−0.103***	−0.118***	−0.122***	−0.105***	−0.102***	−0.105***	−0.108***
LOG_BTM	−0.022	−0.027	−0.023	−0.02	−0.026	−0.024	−0.034	−0.045
INTEREST_COV	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.003***
ROIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STR	0.000							
CON	0.000							
STR_CG		−0.006*						
CON_CG		0						
STR_COM			0.000					
CON_COM			0.003					
STR_DIV				0.000				
CON_DIV				−0.006				
STR_EMP					0.005			
CON_EMP					−0.001			
STR_ENV						−0.005*		
CON_ENV						0.007**		
STR_HR							0.002	
CON_HR							−0.004	
STR_PRO								−0.002
CON_PRO								0.000
CONS	1.413***	1.378***	1.440***	1.460***	1.385***	1.379***	1.382***	1.459***
N	1649	1652	1640	1649	1639	1641	1642	1645
R^2	0.123	0.122	0.124	0.126	0.123	0.127	0.12	0.12
R^2_adj.	0.120	0.118	0.12	0.122	0.12	0.123	0.116	0.116

***, **, * denote 0.01, 0.05 and 0.10 significance levels, respectively.

governance controversies on creditors' perception may be offset by the positive effect of CSR reporting quality. Therefore, besides controlling for measurement bias, our study needs to be supported by deeper investigations that not only look at CSR disclosure quality but more importantly at the effect of CSR governance control mechanisms effectiveness (see Bhojraj and Sengupta 2003; Ashbaugh-Skaife, Collins et al., 2006). Second, Table 3 reports a negative coefficient for environmental strengths (−0.005 at 10% level) and a positive coefficient for environmental concerns (0.007 at 5% level). They show that an increase of one point in KLD's environmental strengths scoring (ENV_STR) and a decrease of one unit in environmental concerns (ENV_CON) will lead to an expected decrease of 0,5% and 0,7% in the cost of debt, respectively. These results are in line with prior findings suggesting that a pro-environmental management reduces the CoD. More importantly, they validate our proposition that the presence of environmental concerns increases firms' CoD. Accordingly, we accept hypothesis H2. However the low coefficient reported in our study suggests that environmental risk remains a negligible factor in the assessment of firm's global risk by creditors (Table 5).

The low R^2 recorded for our regressions limits the scope of our findings. Our models fail to fully explain the CoD variance. The presence of a significant high intercept (1.4 at 1% level) suggests the existence of determinant unobserved firm-specific factors. In panel data studies, industry class is often described as a possible factors determining firm-level fixed effect. In their study, Gebhardt et al. (2001) found that industry membership affects the cost of capital among publicly held firms. Minton and Schrand (1999) note that risk management costs (and thus external capital costs) are likely to be low for firms in the oil and gas, mining, and agriculture industries where liquid, well-developed derivatives markets exist for a risk that represents a significant source of firm's cash flow volatility. Industry membership is also presented as a significant determinant of the relationship between firms' environmental performance and their financial risks' appreciation as suggested by the several studies focusing on industrial highly polluting sectors (see for e.g. Clarkson et al., 2004; Clarkson et al., 2011). Sharfman and Fernando (2008) add that the level of environmental risk exposure varies across the different industries leading to a spurious correlation between environmental performance and the CoD. We thus consider important to test the robustness of our results by controlling for industry-specific effects.

5. Robustness test

There are a variety of ways to assess industry effects. In this study, we use the approach previously conducted by Sharfman and Fernando (2008). Precisely, we used the Standard Industrial Classification (SIC) code in the form of dummy variables to identify each firm's core sector membership. Due to missing data our initial sample was reduced to 212 firms. Because of the size of our dataset and the high number of two-digit SIC codes represented in the sample (41), adding the appropriate number of dummy variables was not feasible. Accordingly and similar to Sharfman and Fernando (2008) we first analyzed the covariance (ANOVA) of the two-digit SIC codes distribution and the CoD as the dependent variable. There was a significant effect, so we ran a pair wise post hoc analysis using Bartlett's test and report three different comparison tests[9] to determine which industry groups were different. This analysis is more likely to find differences among groups (be less conservative) as it does not assume equal variance across cells. The test revealed that two industry groups were not homogeneous with the other groups[10] so we created a dummy variable IND_DUM to categorize the belonging or non-belonging to these two non-homogeneous groups. This resulted in 12 firms in the non homogeneous group and 200 in the homogeneous group and we used this dummy variable as described by the following model.

$$LOG\_CoDit = \alpha + \beta 0LOG\_LEVERAGE\ \ it + \beta 1LOG\_SIZE\ \ it + \beta 2LOG\_BTM\ \ it + \beta 3INTEREST\ \ it + \beta 4ROIC\ \ it + \beta 5STR\ \ it + \beta 6CON\ it + \beta 7IND\_DUM\ it + \varepsilon\ (2a)$$ [11]

Contrarily to our assumption, Table 6 reports no specific industry effect on the CoD and confirms the robustness of our original loadings. We observe a slight increase in significance levels reported for the coefficients related to governance and environmental indicators.

6. Conclusion

Despite the well-developed literature on the corporate social performance – cost of capital relationship, very few large-sample empirical studies examine how a firm's CSP affect its cost of debt. In this research, after accounting for the multiple criticisms dealing with the relevance and reliability of CSP construct and measurement (Johnson and Greening, 1999; Mattingly and Berman, 2006; Mitnick, 2000; Szwajkowski and Figlewicz, 1997), we chose to isolate the constituents of CSP proven to have sound operational implication in firms' default risk, namely governance and environmental concerns. We investigated the relationship between these constituents and the CoD for a sample of 214 U.S firms. By testing the CSP-CoD association, we tried to ascertain whether the operational implications of governance and environmental issues impact firms' default and bankruptcy risks' perception by creditors.

Our study makes a significant methodological improvement as compare to prior works. Based on prior authors' recommendations (Mattingly and Berman, 2006; Sharfman, 1996), we choose to rely on disaggregated measures of CSP to verify expected predictions dealing with the presence of firms' governance and environmental controversies. We distinguish between the two dimension of KLD's CSP measurement, namely *strengths* and *concerns*.

First, in line with our prediction, our results show that environmental concerns increase creditors' perception of firms' default risk as measured by their cost of debt. They also confirm the conclusions of Schneider (2011) and, Sharfman and Fernando (2008) concerning the negative relationship between environmental strengths and firms' cost of debt. Second, the results report no significant effects of corporate governance controversies on the CoD. This result was counterintuitive with regard to the significant negative effect of governance strengths observed in this study and previously reported in different works (Fich and Slezak, 2008; Goss, 2009; Sengupta, 1998). We interpret this "governance paradox" with regard to the construct of KLD's governance strengths' scoring which is exclusively determined by CSR reporting[12] quality. We suggest that the negative perception of governance controversies by creditors may be offset by the positive perception of a good CSR reporting, often used by controversial firms to

[9] Namely Sidak, Bonferroni and Scheffe.

[10] Barltlett's test confirmed that at least two industry group variances were different. The three comparisons tests of Sidak, Bonferroni and Scheffe reported that the variances of industry group identified by SIC codes 35 and 74 are different from the rest of industry groups' variances (all significant at the 0.01% level).

[11] Similarly model 2b reproduces model 1b with industry dummies in addition

[12] For more details see the 2011 MSCI ESG Research rating methodology.

Table 6
Results of the regression analysis with industry correction; dependent variable: CoD.

Variables	Model 2a: Composite CSP	Model 2b: Disaggregated measure of CSP						
LOG_LEVERAGE	−0.101***	−0.100***	−0.099***	−0.100***	−0.100***	−0.102***	−0.100***	−0.129***
LOG_SIZE	−0.112***	−0.106***	−0.123***	−0.128***	−0.109***	−0.106***	−0.110***	−0.113***
LOG_BTM	−0.03	−0.04	−0.03	−0.03	−0.04	−0.04	−0.05	−0.054*
INTEREST_COV	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.003***
ROIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INDUSTRY	0.025	0.024	0.024	0.025	0.024	0.025	0.035	0.024
STR	−0.001							
CON	0.000							
STR_CG		−0.008**						
CON_CG		−0.001						
STR_COM			−0.001					
CON_COM			0.002					
STR_DIV				0.000				
CON_DIV				−0.007*				
STR_EMP					0.001			
CON_EMP					−0.002			
STR_ENV						−0.007**		
CON_ENV						0.006**		
STR_HR							0.003	
CON_HR							−0.004	
STR_PRO								−0.003
CON_PRO								0.001
CONS	1.394***	1.362***	1.430***	1.455***	1.374***	1.367***	1.370***	1.446***
N	1465.00	1468.00	1456.00	1465.00	1455.00	1457.00	1458.00	1461.00
R^2	0.12	0.12	0.12	0.13	0.12	0.13	0.12	0.11
R^2_adj.	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11

***, **, * denote 0.01, 0.05 and 0.10 significance levels, respectively.

“greenwash” their concerns as explained by the *legitimacy theory* (Deegan et al., 2002; O’Donovan, 2002). Finally, to ensure the reliability of our results, we have conducted a robustness test that revealed no industry or firm specific bias.

Acknowledgment

This work is part of a research project funded by the Chair AG2R LA MONDIALE.

References

Agrawal, A., Nagarajan, N.J., 1990. Corporate capital structure, agency costs, and ownership control: the case of all-equity firms. J. Finance 45 (4), 1325–1331.
Aldamen, H., Duncan, K., 2012. Does adopting good corporate governance impact the cost of intermediated and non-intermediated debt? Account. Finance 52, 49–76.
Altman, E.I., Hotchkiss, E., 2006. Corporate Financial Distress and Bankruptcy: Predict and Avoid Bankruptcy, Analyze and Invest in Distressed Debt, vol. 289 Wiley. com.
Altman, E.I., Gande, A., Saunders, A., 2010. Bank debt versus bond debt: evidence from secondary market prices. J. Money Credit Bank. 42 (4), 755–767.
Aman, H., Nguyen, P., 2013. Does good governance matter to debtholders? Evidence from the credit ratings of Japanese firms. Res. Int. Bus. Finance 29, 14–34.
Anderson, R.C., Mansi, S.A., Reeb, D.M., 2004. Board characteristics, accounting report integrity, and the cost of debt. J. Account. Econ. 37 (3), 315–342.
Andrade, S.C., Bernile, G., Hood Iii, F.M., 2014. SOX, corporate transparency, and the cost of debt. J. Bank. Finance 38, 145–165.
Ang, J.S., Chua, J.H., McConnell, J.J., 1982. The administrative costs of corporate bankruptcy: a note. J. Finance 37 (1), 219–226.
Aragon-Correa, J.A., 1998. Strategic proactivity and firm approach to the natural environment. Acad. Manage. J. 41 (5), 556–567.
Ashbaugh-Skaife, H., Collins, D.W., Lafond, R., 2006. The effects of corporate governance on firms’ credit ratings. J. Account. Econ. 42 (1–2), 203–243.
Barnea, A., Rubin, A., 2010. Corporate social responsibility as a conflict between shareholders. J. Bus. Ethics 97 (1), 71–86.
Barnett, M.L., Salomon, R.M., 2011. Does it pay to be really good? Addressing the shape of the relationship between social and financial performance. Strateg. Manage. J. 33 (11), 1304–1320.
Baxter, N.D., 1967. Leverage, risk of ruin and the cost of capital. J. Finance 22 (3), 395–403.
Bedard, J.C., Johnstone, K.M., 2004. Earnings manipulation risk, corporate governance risk, and auditors’ planning and pricing decisions. Account. Rev. 79 (2), 277–304.
Bhojraj, S., Sengupta, P., 2003. Effect of corporate governance on bond ratings and yields: the role of institutional investors and outside directors. J. Bus. 76 (3), 455–475.
Caouette, J.B., Altman, E.I., Narayanan, P., Nimmo, R., 2011. Managing Credit Risk: The Great Challenge for Global Financial Markets, vol. 401 John Wiley & Sons.
Carroll, A.B., 1979. A three-dimensional conceptual model of corporate performance. Acad. Manage. Rev. 4 (4), 497–505.
Carroll, A.B., 1999. Corporate social responsibility evolution of a definitional construct. Bus. Soc. 38 (3), 268–295.
Cellier, A., Chollet, P., 2016. The effects of social ratings on firm value. Res International Bus. Finance. 36, 656–683.
Chatterji, A.K., Levine, D.I., Toffel, M.W., 2009. How well do social ratings actually measure corporate social responsibility? J. Econ. Manage. Strategy 18 (1), 125–169.
Clarkson, P.M., Li, Y., Richardson, G.D., 2004. The market valuation of environmental capital expenditures by pulp and paper companies. Account. Rev. 79 (2), 329–353.
Clarkson, P.M., Li, Y., Richardson, G.D., Vasvari, F.P., 2011. Does it really pay to be green? Determinants and consequences of proactive environmental strategies. J. Account. Publ. Policy 30 (2), 122–144.
Coulson, A.B., Monks, V., 1999. Corporate environmental performance considerations within bank lending decisions. Corp. Soc. Responsib. Environ. Manage. 6 (1), 1.
Dawkins, C.E., Fraas, J.W., 2013. An exploratory analysis of corporate social responsibility and disclosure. Bus. Soc. 52 (2), 245–281.

Deegan, C., Rankin, M., Tobin, J., 2002. An examination of the corporate social and environmental disclosures of BHP from 1983 to 1997: a test of legitimacy theory. Account. Audit. Account. J. 15 (3), 312–343.
Delmas, M., Blass, V.D., 2010. Measuring corporate environmental performance: the trade-offs of sustainability ratings. Bus. Strategy Environ. 19 (4), 245–260.
Diamond, D.W., 1984. Financial intermediation and delegated monitoring. Rev. Econ. Stud. 51 (3), 393–414.
Donaldson, L., 1998. Performance-Driven Organizational Change: The Organizational Portfolio. Sage.
El Ghoul, S., Guedhami, O., Kwok, C.C.Y., Mishra, D.R., 2011. Does corporate social responsibility affect the cost of capital? J. Bank. Finance 35 (9), 2388–2406.
Escrig-Olmedo, E., Muñoz-Torres, M.J., Fernández-Izquierdo Á, M., Rivera-Lirio, J.M., 2017. Measuring corporate environmental performance: a methodology for sustainable development. Bus. Strategy Environ. 26 (2), 142–162.
Fich, E.M., Slezak, S.L., 2008. Can corporate governance save distressed firms from bankruptcy? An empirical analysis. Rev. Quant. Finance Account. 30 (2), 225–251.
Frooman, J., 1997. Socially irresponsible and illegal behavior and shareholder wealth a meta-analysis of event studies. Bus. Soc. 36 (3), 221–249.
Fung, A., Graham, M., Weil, D., 2007. Full Disclosure: The Perils and Promise of Transparency. Cambridge University Press.
Galema, R., Plantinga, A., Scholtens, B., 2008. The stocks at stake: return and risk in socially responsible investment. J. Bank. Finance 32 (12), 2646–2654.
Gebhardt, W.R., Lee, C., Swaminathan, B., 2001. Toward an implied cost of capital. J. Account. Res. 39 (1), 135–176.
Goss, A., Roberts, G.S., 2011. The impact of corporate social responsibility on the cost of bank loans. J. Bank. Finance 35 (7), 1794–1810.
Goss, A., 2009. In: Corporate Social Responsibility and Financial Distress. Paper presented at the ASAC.
Gruber, M.J., Warner, J.B., 1977. Bankruptcy costs: some evidence. J. Finance 32 (2), 337–347.
Hart, S.L., Ahuja, G., 1996. Does it pay to be green? An empirical examination of the relationship between emission reduction and firm performance. Bus. Strategy Environ. 5 (1), 30–37.
Hayward, R., Lee, J., Keeble, J., McNamara, R., Hall, C., Cruse, S., et al., 2013. The UN global compact-accenture CEO study on sustainability 2013. UN Glob. Compact Rep. 5 (3), 1–60.
Hong, H., Kacperczyk, M., 2009. The price of sin: the effects of social norms on markets. J. Financ. Econ. 93 (1), 15–36.
Jensen, M.C., Meckling, W.H., 1976. Theory of the firm: managerial behavior, agency costs and ownership structure. J. Financ. Econ. 3 (4), 305–360.
Johnson, R.A., Greening, D.W., 1999. The effects of corporate governance and institutional ownership types on corporate social performance. Acad. Manage. J. 42 (5), 564–576.
Jorion, P., 2007. Financial Risk Manager Handbook, vol. 406 John Wiley & Sons.
Kang, J., 2015. Effectiveness of the KLD social ratings as a measure of workforce diversity and corporate governance. Bus. Soc. 54 (5), 599–631.
Kempf, A., Osthoff, P., 2007. The effect of socially responsible investing on portfolio performance. Eur. Financ. Manage. 13 (5), 908–922.
Khanna, M., Damon, L.A., 1999. EPA's voluntary 33/50 program: impact on toxic releases and economic performance of firms. J. Environ. Econ. Manage. 37 (1), 1–25.
Kim, Y., 2013. Environmental, sustainable behaviors and innovation of firms during the financial crisis. Bus. Strategy Environ. 24 (1), 58–72.
Klock, M.S., Mansi, S.A., Maxwell, W.F., 2005. Does corporate governance matter to bondholders? J. Financ. Quant. Anal. 40 (04), 693–719.
Laufer, W.S., 2003. Social accountability and corporate greenwashing. J. Bus. Ethics 43 (3), 253–261.
Margolis, J., Elfenbein, H., Walsh, J., 2007. Does it pay to be good? A meta-analysis and redirection of research on the relationship between corporate social and financial performance. In: Academy of Management Conference. Philadelphia.
Mattingly, J.E., Berman, S.L., 2006. Measurement of corporate social action discovering taxonomy in the Kinder Lydenburg Domini ratings data. Bus. Soc. 45 (1), 20–46.
Mattingly, J.E., 2017. Corporate social performance: a review of empirical research examining the corporation—society relationship using Kinder, Lydenberg, Domini social ratings data. Bus. Soc. 56 (6), 796–839.
McGuire, J.B., Sundgren, A., Schneeweis, T., 1988. Corporate social responsibility and firm financial performance. Acad. Manage. J. 31 (4), 854–872.
Mengze, H., Wei, L., 2015. A comparative study on environment credit risk management of commercial banks in the Asia-Pacific region. Bus. Strategy Environ. 24 (3), 159–174.
Minton, B.A., Schrand, C., 1999. The impact of cash flow volatility on discretionary investment and the costs of debt and equity financing. J. Financ. Econ. 54 (3), 423–460.
Mitnick, B.M., 2000. Commitment, revelation, and the testaments of belief: the metrics of measurement of corporate social performance. Bus. Soc. 39 (4), 419.
Moskowitz, M., 1972. Choosing socially responsible stocks. Bus. Soc. Rev. 1 (1), 71–75.
Nikolaev, V., Van Lent, L., 2005. The endogeneity bias in the relation between cost-of-debt capital and corporate disclosure policy. Eur. Account. Rev. 14 (4), 677–724.
Nooteboom, B., Berger, H., Noorderhaven, N.G., 1997. Effects of trust and governance on relational risk. Acad. Manage. J. 40 (2), 308–338.
O'Donovan, G., 2002. Environmental disclosures in the annual report: extending the applicability and predictive power of legitimacy theory. Account. Audit. Account. J. 15 (3), 344–371.
Orlitzky, M., Benjamin, J.D., 2001. Corporate social performance and firm risk: a meta-analytic review. Bus. Soc. 40 (4), 369–396.
Orlitzky, M., Schmidt, F.L., Rynes, S.L., 2003. Corporate social and financial performance: a meta-analysis. Organ. Stud. (01708406) 24 (3), 403–441.
Porter, M.E., Kramer, M.R., 2006. The link between competitive advantage and corporate social responsibility. Harv. Bus. Rev. 11.
Porter, M.E., Van der Linde, C., 1995. Toward a new conception of the environment-competitiveness relationship. J. Econ. Perspect. 9 (4), 97–118.
Rajan, R.G., Zingales, L., 1996. Financial Dependence and Growth. National Bureau of Economic Research.
Rowley, T., Berman, S., 2000. A brand new brand of corporate social performance. Bus. Soc. 39 (4), 397–418.
Russo, M.V., Fouts, P.A., 1997. A resource-based perspective on corporate environmental performance and profitability. Acad. Manage. J. 40 (3), 534–559.
Schneider, T.E., 2011. Is environmental performance a determinant of bond pricing? Evidence from the U.S. pulp and paper and chemical industries. Contemp. Account. Res. 28 (5), 1537–1561.
Scholtens, B., Zhou, Y., 2008. Stakeholder relations and financial performance. Sustain. Dev. 16 (3), 213–232.
Scholz, R.W., Weber, O., Michalik, G., 1995. Ecological risks in commercial credit business. In: O.-K.D (Ed.), Credit Risks Caused by Environmental Risks. Economica and Deutscher Sparkassenverlag, Bonn (pp. 1–49).
Sengupta, P., 1998. Corporate disclosure quality and the cost of debt. Account. Rev. 73 (4), 459–474.
Sharfman, M.P., Fernando, C.S., 2008. Environmental risk management and the cost of capital. Strateg. Manage. J. 29 (6), 569–592.
Sharfman, M., 1996. The construct validity of the Kinder, Lydenberg & Domini social performance ratings data. J. Bus. Ethics 15 (3), 287–296.
Shrivastava, P., 1995. Environmental technologies and competitive advantage. Strateg. Manage. J. 16 (S1), 183–200.
Sun, W., Cui, K., 2014. Linking corporate social responsibility to firm default risk. Eur. Manage. J. 32 (2), 275–287.
Szwajkowski, E., Figlewicz, R.E., 1997. Of babies and bathwater an extension of the business & society research forum on the fortune reputation database. Bus. Soc. 36 (4), 362–386.
Thompson, P., Cowton, C.J., 2004. Bringing the environment into bank lending: implications for environmental reporting. Br. Account. Rev. 36 (2), 197–218.
Titman, S., Wessels, R., 1988. The determinants of capital structure choice. J. Finance 43 (1), 1–19.
Turban, D.B., Greening, D.W., 1997. Corporate social performance and organizational attractiveness to prospective employees. Acad. Manage. J. 40 (3), 658–672.
Van der Laan, G., Van Ees, H., Van Witteloostuijn, A., 2008. Corporate social and financial performance: an extended stakeholder theory, and empirical test with accounting measures. J. Bus. Ethics 79 (3), 299–310.
Waddock, S.A., Graves, S.B., 1997. The corporate social performance. Strateg. Manage. J. 8 (4), 303–319.
Weber, O., Fenchel, M., Scholz, R.W., 2008. Empirical analysis of the integration of environmental risks into the credit risk management process of European banks. Bus. Strategy Environ. 17 (3), 149–159.
Weber, O., Scholz, R.W., Michalik, G., 2010. Incorporating sustainability criteria into credit risk management. Bus. Strategy Environ. 19 (1), 39–50.
Weber, O., 2012. Environmental credit risk management in banks and financial service institutions. Bus. Strategy Environ. 21 (4), 248–263.
Wood, D.J., Jones, R.E., 1995. Stakeholder mismatching: a theoretical problem in empirical research on corporate social performance. Int. J. Organ. Anal. 3 (3), 229–267.
Wood, D.J., 2010. Measuring corporate social performance: a review. Int. J. Manage. Rev. 12 (1), 50–84.

Annex 544

J. S. Hess and I. Kelman, “Tourism Industry Financing of Climate Change Adaptation: Exploring the Potential in Small Island Developing States”, *Climate, Disaster and Development Journal*, 2017, pp. 33-45

Climate,
Disaster and
Development
Journal
Open access peer-reviewed papers

Tourism Industry Financing of Climate Change Adaptation: Exploring the Potential in Small Island Developing States

Janto S. Hess[1,2] · Ilan Kelman[1,3,4]

[1]*Institute for Risk and Disaster Reduction at University College London*
[2]*Earth System Governance Project*
[3]*Institute for Global Health, University College London*
[4]*University of Adger*

Received: 12 November 2016 / Accepted: 17 July 2017 / Published online: 25 July 2017

Abstract

In many small island developing states (SIDS), tourism is a principal driver of the economy and of infrastructure development. The SIDS' tourism sector is, however, threatened by climate change impacts, which will likely incur high costs for climate change adaptation (CCA). Discussions are starting about who should pay for the costs of adapting to climate change, especially the balance amongst sectors such as between governments and the tourism industry. Through the perceptions of selected industry stakeholders, this study explores the potential of the tourism industry in SIDS in financing its own CCA. Fiscal and political mechanisms were examined, such as adaptation taxes and levies, adaptation funds, building regulations, and risk transference. The study's exploratory method combines nine in-depth key stakeholder interviews from various SIDS and an extensive literature review to develop a schematic of suggested mechanisms. The results reveal a high overall potential for the tourism industry funding its CCA, but with significant challenges in realizing this potential. Consumer expectations and demands, governmental hesitation in creating perceived investment barriers, and assumptions about cost effectiveness could undermine steps moving forward. Varying incentive structures, the sector's price sensitivity, and the differing abilities of tourism industry stakeholders to adapt are factors suggesting that government frameworks are needed to ensure effective and substantive action.

Keywords: Climate change · adaptation · climate finance · islands · SIDS · small island developing states

DOI: https://doi.org/10.18783/cddj.v002.i02.a04

Corresponding Author:
Janto S. Hess
Janto.Hess.15@ucl.ac.uk

Introduction

Small Island Developing States or SIDS are several countries said to have similar development challenges and opportunities (United Nations Framework Convention on Climate Change [UNFCCC], 2007). They are particularly vulnerable to climate change, especially to impacts such as sea-level rise, changing frequencies and intensities of weather extremes, coastal flooding and erosion, and ocean acidification (UNFCCC, 2015; Nurse et al., 2014); but they also display significant resilience to challenges faced (Gaillard, 2007; Lewis, 1999), albeit with significant financial burden on their governments and economic sectors to adapt to and recover from climate change impacts.

To help cope with these costs, USD 100 billion of international climate finance was pledged annually from 2020 onwards to support developing countries in tackling climate change impacts, with SIDS prioritized as recipients (UNFCCC, 2015). The USD 100 billion is supposed to come from both private and public sources, yet the private sector's involvement remains unclear and creates challenges (United Nations Environmental Programme [UNEP], 2016; Dzebo & Pauw, 2014). Available data on private sector contributions to adaptation is sparse (Brown et al., 2015; Buchner, Trabacchi, Mazza, Abramskiehn, & Wang, 2015). Buchner et al. (2015) estimated an overall contribution by the private sector of USD 245 billion in 2014 for dealing with climate change.

Many SIDS are experiencing climate change impacts and need financial resources to adapt (Intergovernmental Panel on Climate Change [IPCC], 2014a). Climate change adaptation (CCA) is "[t]he process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities" (IPCC, 2014b, p. 118). CCA finance is understood as comprising all financial resources that are mobilised, pledged, or spent on adaptation.

One of the main economic sectors for many SIDS (Connell, 2013; United Nations World Tourism Organization [UNWTO], 2012; Scheyvens & Momsen, 2008) is tourism, which is considered as one of the biggest global industries (UNWTO, 2016). SIDS governments frequently support the tourism industry financially, including paying for development, due to its assumed benefits such as generating employment, fostering development, generating tax revenues, and justifying the value of protecting natural resources. But climate change is projected to exacerbate existing development challenges, such as fresh water supply and infrastructure resilience to storms, indicating the need for the tourism industry to adapt (Scott, Hall, & Gössling, 2016; IPCC, 2014a; Scott, Gössling, & Hall, 2012; UNWTO, UNEP, & World Meteorological Organization [WMO], 2008). This setting leads to an inquiry whether it is the SIDS' governments or the tourism industry that should pay for all CCA initiatives in the tourism industry, or if these costs should be shared between them.

The SIDS tourism industry could be encouraged to support adaptation financing due to its dependency on SIDS' destination attributes and activities, such as beaches and diving. Other concerns could also emerge, providing impetus for supporting adaptation financing. In some SIDS locations, tourists' use of water and energy is a concern or tackling eroding shorelines is priority. Consequently, multiple reasons might emerge, but the short-term thinking of some sector stakeholders needs to be considered, in that parts of the tourism industry might be seeking the quickest way of achieving maximum profit.

This paper explored the potential for involving the tourism industry in SIDS to fund its own CCA by examining views of potential roles which the industry could play.

SIDS in the Context of International Tourism and Climate Change

In many SIDS, the tourism industry generates a significant share of the country's gross domestic product (GDP). For example, tourism share was estimated at 76.8% of GDP in Palau in 2012 (Central Intelligence Agency [CIA], 2014), at 47.3% in Vanuatu in 2015 (World Travel and Tourism Council [WTTC], 2016b) and at 38.7% in Fiji in the same year (WTTC, 2016a). Tourism is often perceived as a key development option for SIDS, especially when exports face significant constraints due to high transportation costs, market entry barriers, and unfavourable trade agreements (UNWTO, 2012; Brau, Liberto, & Pigliaru, 2011; Bishop, 2010; Narayan, Narayan, Prasad, &Prasad, 2010; Croes, 2006). However, tourism markets are particularly vulnerable to sudden changes, such as from the global economy, perceptions of political unrest and violence, and media portrayals of adverse environmental impacts (Connell, 2013; Graci & Dodds, 2010). The impacts of specific events on visitor numbers can be short-lived, but structural or long-term changes, such as from climate change, can significantly alter a destination's perceived or actual functionality and appeal (Mahon, Becken, & Rennie, 2013; Narayan et al., 2010; Gössling, Bredberg, Randow, Sandstrom, & Svensson, 2006).

Projected climate change impacts on SIDS include changing patterns of weather extremes, water scarcity, biodiversity loss, sea-level rise, and ocean acidification (c.f. IPCC, 2014a; Gössling et al., 2012; Scott et al., 2012; Becken & Hay, 2007). Table 1 shows how such impacts can affect the tourism sector, especially through reputational risks, threatening the attractiveness of SIDS as tourist destinations or perceptions thereof (Shakeela & Becken, 2015; Mahon et al., 2013; Wright, 2013; Gössling et al., 2006). Ironically, the demand for this market segment, and government policies to support it, produces a pattern of coastal zone tourism development that can further increase the place's vulnerability to weather extremes (Juhasz, Ho, Bender, & Fong, 2010; Allison, 1996).

Table 1. Illustrative impacts of climate change on tourism in SIDS (based on IPCC, 2014a; Scott et al., 2012; UNWTO et al., 2008)

Climate change effect	Tourism impacts	Tourism impacts
Sea-level rise	Coastal erosion, beach loss	Clearing coastal areas of vegetation,

Table 1 *(Continued)*

Climate change effect	Tourism impacts	Tourism impacts
Sea-level rise *(Continued)*		artificial beach nourishment
A changing storm regime	Damage to tourism facilites, increased insurance costs, business interruption	Developing tourism infrastructure in hazard-prone areas, poor quality of building design and materials, insufficient disaster risk reduction and disaster management
Biodiversity changes	Loss of natural attractions and species from destinations, especially for coral reefs	Pollution, poor waste and waste-water management, disturbance of animals in protected areas, reduction of and damage to natural habitats
Warmer temperatures	Heat stress for tourists, increased cooling costs, coral bleaching	Inadequate building design, reduction of tree cover and natural shading options

Private Sector Involvement in Climate Adaptation Finance

After the initial pledge to provide USD 100 billion annually by 2020, private sector involvement in adaptation finance was increasingly highlighted (UNEP, 2016; Pauw & Pegels, 2013; Atteridge, 2011). In this article, the term 'private sector' is primarily understood as any privately-owned enterprise. The private sector will likely have to adapt, and in many cases already adapts, to climate change through exploiting new business opportunities and managing climate-related risks (Pauw, 2015; Surminski, 2013). Tracking private finance in adaptation is a major challenge due to scarcity of information (Pauw, 2015; Agrawala et al., 2011).

Much investment in adaptation is not officially declared, tracked, or labelled as such, instead takes place through incremental changes and adjustments of infrastructure and responses to changing demand patterns (Christiansen, Ray, Smith, & Haites, 2012). Having little data does not mean an absence of adaptation investments. Case studies verify that adaptation and its financing take place on different levels, e.g., by small- and medium-sized enterprises (UNFCCC, 2014; Bradshaw, Dolan, & Smit, 2004; Qiu & Prato, 2012) and by large companies (UNFCCC, 2016; Kolk & Pinkse, 2005).

There was a proposal to raise USD 8 to 10 billion annually through an International Air Passenger Adaptation Levy (IAPAL) for financing adaptation in developing countries (Müller, 2008). In 2008, the UN's group of Least Developed Countries proposed to include the IAPAL within the UNFCCC Bali Action Plan, but they did not succeed (Scott & Becken, 2010). The proposal shows that the tourism sector has some potential for becoming a major source of adaptation financing. Concerns were raised, however, about possible impacts of such a levy on global air travel dynamics and its consequences for tourism-dependent SIDS. Nevertheless, one investigation concluded that "the potential benefits of IAPAL for countries reliant on tourism are likely to outweigh the costs of slightly reduced tourist numbers" (Chambwera, Njewa, & Loga, n.d., p. 12), implying that the industry would not be harmed by such a levy and that industry supporting the levy would see an adequate return on investment.

In the end, the private sector "will expect the same return on their investment ['risk premium'] in adaptation that is available from other investments with a similar risk profile" (Christiansen et al., 2012, p. 8). Uncertainties for tourism in SIDS include: (i) unclear magnitudes and time scales of regional and local climate change impacts; (ii) public policy changes and reliability; (iii) political instability; (iv) development of international tourism flows; (v) non-transparent and unreliable political systems; and (vi) limited ability and experience for diversifying risks amongst different economic sectors (Transparency International, 2016; Ackerman & Stanton, 2013; Buchner et al., 2013; Connell, 2013; Wong, de Lacy, & Jiang, 2007; Schelling, 2007). In other words, the largest uncertainties come from human responses to climate change rather than from climate change itself, which is a challenge for the private sector to respond to when many of the responses are government-led.

Methodology

This exploratory study is based on a mixed methods approach and brings together findings from the literature and a stakeholder approach comprising nine semi-structured, in-depth interviews. An initial literature review and analysis identified six mechanisms which are relevant and feasible for involving the tourism industry in financing its own adaptation. An in-depth literature review ensued.

In terms of the stakeholder approach and within the context of climate change uncertainties and how humanity might respond to the impacts, stakeholder theory can further enrich the understanding of the potential interest and perspectives of the tourism industry in financing its adaptation. A stakeholder is "any group or individual who can affect or is affected by the achievement or the organisation's objective" (Freeman, 1984, p. 46). Stakeholder theory can be understood as "a theory of organizational management and ethics" exploring the interaction between a company and their stakeholders (Phillips, Freeman, & Wick, 2003, p. 480). A range of papers has debated if the natural environment, and as a part of it climate change, could be considered as being a stakeholder, with some arguing for it (e.g., Haigh & Griffiths, 2009; Kolk & Pinkse, 2005; Starik, 1995) and some against it (e.g., Orts & Strudler, 2002; Phillips & Reichart, 2000).

Given this debate, it is important to acknowledge that the natural environment and climate change impacts must be considered in businesses' strategic management processes (Haigh & Griffiths, 2009). Due to the relatively small land and population size of SIDS, there tends to be fewer stakeholders overall, especially in the private sector, meaning that any given stakeholder's actions or reactions can lead to comparatively bigger domestic impacts than in other countries. Thus, for enterprises in a SIDS context, incorporating their stakeholders' climate change impacts and adaptation actions is of strategic interest, since the close interdependencies amongst the stakeholders mean that one stakeholder's decisions can have significant ripple effects around the country.

Using the stakeholder approach, the in-depth interviews explored potential attributes and perceptions of selected stakeholders in the industry on the mechanisms and CCA financing more generally. Many papers examining international tourism have used a comparable number of qualitative, in-depth interviews, demonstrating how a small but targeted sample size can lead to rich findings (Osorio & Best, 2015; Mansfeld & Korman, 2015; Wong et al., 2012).

The interviews were conducted in person (five participants) and via Skype (four participants) during two months in mid-2014, completed in English (common language of the interviewer and all interviewees), based on open-ended and follow-up questions, and lasted 45 minutes on average. All interview partners were offered anonymity, an option accepted by only the tour operator representatives. Table 2 provides an overview of the interviewees. These individuals were selected based on their (i) expertise on the topic and (ii) representing a broad range of stakeholders from the tourism industry, donor organisations, and local governments. Most interviews with government representatives were conducted at an international climate change negotiations event in Bonn. The other interviewees were identified through reviewing existing literature and recommendations from other interviewees (snowball sampling).

Table 2. Overview of interviewees

Abbr	Operating Location	Institution	Position
SL	St. Lucia	Ministry of Sustainable Development, Energy, Science and Technology	Chief Sustainable Development & Environment Officer
PNG	Papua New Guinea	Office of Climate Change and Development, Government of PNG	Manager of Reducing Emissions from Deforestation and Forest Degradation Projects
MA	Mauritius	Ministry of Environment & Sustainable Development	Divisional Environment Officer
SI	Solomon Islands	Ministry of Environment, Climate Change, Disaster Management and Meteorology	Under Secretary / Technical
UN	Mauritius	United Nations Development Programme	Regional Technical Adviser
UNW	South East Asia	United Nations World Tourism Organization, Consulting Unit on Tourism and Biodiversity	Project Manager, Sustainable Development for Tourism
TO1	Carribean, Africa, Indian Ocean	Tourism Operator 1, multinational tourism corporation within the range of the 5 biggest tour operators in Europe	Head of Sustainability Management
TO2	Carribean, Africa, Indian Ocean	Tour Operator 2, multinational tourism corporation within the range of the 5 biggest tour operators in Europe	Higher Management
WT	Globally	World Travel and Tourism Council	Policy and Research Director

The semi-structured interviews were recorded, transcribed, coded, and analysed qualitatively (Liamputtong, 2013; Bryman, 2012; Babbie, 2010) to extract details for and interviewees' perceptions regarding each investigated mechanism. The findings were further enriched through a targeted literature search identifying existing examples and attributes of each mechanism. The main limitation of the data is the underrepresented tourism industry stakeholders, such as from accommodation, boating, and diving; however, the interviewees indicated that they work closely with these sectors and revealed insights into their perceptions, helping to overcome this gap.

Mechanisms for Involving the Tourism Industry in Adaptation Finance

The results demonstrated stakeholder perceptions of CCA financing for the tourism industry and provided details of six mechanisms for involving the industry in financing its adaptation, namely: (i) public-private partnerships (PPPs); (ii) building standards and regulations; (iii) adaptation taxes or levies; (iv) adaptation funds; (v) water use management; and (vi) risk transfer mechanisms.

Perceptions of and on Key Stakeholders

Most interviewees estimated the tourism industry's awareness of climate change as being high. Climate change is apparently recognized by the industry as a big 'trend' that will affect business in the future. At annual business summits of the largest global lobby organisation of the industry, climate change "always comes up whether [they] plan to talk about it or not" (WT). Studies confirmed this perception on climate change of the tourism industry in SIDS (Belle & Bramwell, 2005; Méheux & Parker, 2006).

Awareness does not automatically lead to action. In fact, the overall willingness of the sector to participate in financing CCA was estimated as being low by seven of the nine interviewees, even though it is highly context-dependent. The type of tourism enterprise, their abilities to deal with climate change, and the level of potential benefits of an adaptation measure for their business were key factors shaping the willingness to participate in funding adaptation (TO1, TO2, WT, UNW). The tourism industry representatives also considered governments to be responsible for many adaptation actions (WT, TO2). Another major concern raised by private sector representatives was the transparency of financial flows within local governments (TO1, TO2, WT).

WT, similarly to Pauw & Pegels (2013), raised the question of whether the private sector actually "bothers about" or understands adaptation terminology. They suggested that many enterprises incorporate adaptation measures, and thus fund them, in their daily activities without being aware that they could be termed 'adaptation' or labelling them as such. Other reasons for inactivity (Wright, 2013; Becken & Hay, 2012; Sovacool, 2012; Becken, Hay, & Espiner, 2010; Turton et al., 2010) included: (i) uncertainties about climate change impacts as well as the context of other changes being experienced; (ii) most objects of attraction for tourists being 'common goods' and, therefore, government owned or managed; (iii) the conflicting time horizon of climate projections, regular economic investments, and expectations of return-on-investment; and (iv) the framing of climate change in relation to other more immediate challenges to economic profitability.

The latter could also translate into governmental priority setting. Governments often become more concerned about immediate matters rather than aiming for long-term adaptation strategies, or they need to make policy decisions in a "context of uncertainty and complex socio-economic, cultural, and political relationships" (Belle & Bramwell, 2005; UNW). The government interviewees revealed that they were also cautious about creating extra burdens (or something perceived as such) for the already competitive and price-sensitive tourism industry through taxes and regulations (SL, PNG, MA, SI).

Regardless, adaptation measures would have the highest chance of being implemented when mutual benefits are created, especially in the short-term (UNW, TO1, TO2). The government could aid such a process through reducing uncertainty through legal security, clear public policies, transparency, and incentive frameworks that are influential factors in attracting and sustaining tourism investment (Christiansen et al., 2012; Persson et al., 2009).

Public-Private Partnerships (PPPs)

PPPs can be broadly outlined as arrangements between the public and the private sectors (Hodge & Greve, 2007). There is not a single, widely accepted definition of PPP, but most definitions include it as being a form of collaboration to pool resources for reaching a common aspiration (UNWTO, 2015; Grimsey & Lewis, 2004; Osborne & Murray, 2000; Gray, 1991).

A key determining factor of PPP initiation is expectation of mutually beneficial outcomes, at least in theory. The main incentives for initiating PPPs can be combining specific qualities, such as know-how, of both public and private sectors to create a better result (Rosenau, 2000) by using the innovative capacity of the private sector and potentially garnering additional funding (Christiansen et al., 2012; Hodge & Greve, 2007). In particular for many SIDS with a limited public budget and small development agencies, this can be an important motivation to realize PPP projects. Thus, "PPPs are important, and often vital, elements in the establishment of tourism-based initiatives and the improvement of the market competitiveness of destinations" (UNWTO, 2015, p. 12).

The UNWTO representative saw a high potential for international donors to initiate PPPs for adaptation in SIDS. However, "the extent to which PPP[s] [are currently] employed in climate adaptation is very limited, and even more so in the tourism sector" (Wong et al., 2012, p. 136). Wong et al. (2012, p. 136) investigated "if and how … [PPPs] may help the tourism sector in … [SIDS] in the South Pacific [to] adapt", concluding that the tourism sector stakeholders "were positive about forming PPPs for adaptation" (Wong et al., 2012, p. 140), although one critic did not trust the reliability of the government as a potential partner.

The main barriers to PPPs for the tourism industry were identified as (Wong et al., 2012; WT; Huxham & Vangen, 2002): (i) limited interest in participating financially in projects run by or with stakeholders who can adapt in other ways (TO1, TO2); (ii) setting common aims; (iii) trust; (iv) and differences in work culture. Despite good practice examples, PPPs experienced a range of bad circumstances and were criticized about their effectiveness. This criticism covers: (i) privatizing government assets and services through PPPs which effectively yields ownership to the private sector with limited interest in public goods; (ii) limited transparency; (iii) unsuccessful transfer of risks, and (iv) mainly driven by industry rather than public interests (Roehrich, Lewis, & George, 2014; Sanger & Crawley, 2009; Hodge & Greve, 2007; Hodge, 2004).

Overall, PPPs appear to be a promising mechanism to realize adaptation projects, particularly of large infrastructure interventions. Competing interests, constraints, and stakeholder perceptions need to be factored in when designing measures.
Building Standards and Regulations

High quality building standards for SIDS' tourist infrastructure can significantly decrease the negative impacts of climate change (Mahon et al., 2013). Conversely, the quality of water and resource management can suffer in the absence of regulations. In SIDS, much accommodation was built on or near the seafront in order to fulfil customer desires for beach and water tourism. Thus, tourism developers often took a calculated risk in locating their business on the shoreline, if governmental regulations are absent (Mahon et al., 2013)—and sometimes even when there are governmental regulations against the practice. The tour operator representatives clearly stated that this situation relates to their business practices of cooperating only with resorts close to the shoreline, since tourist demand patterns highlight beachside locations (TO1, TO2).

All countries represented by an interviewee, apart from Mauritius where such laws are currently being drafted, have specific building codes that consider climate change impacts, such as sea-level rise (MA, PNG, SI, SL). From the authors' perspective, there might be a self-selection bias in that representatives from other governments potentially did not make themselves available for interviews due to lack of interest in managing the tourism industry. Yet code enforcement seems to be a major challenge in all the participating countries (SI, SL, MA). Another major issue was that rebuilding tourism infrastructure after disasters often takes place in the same disaster-prone areas (Mahon et al., 2013). Regulatory frameworks to support the industry in dealing with climate change impacts can include monitoring and maintenance regimes within building codes; full planning and design standards and regulations; and professional certification for engineers, architects, and planners. It remained an open question if such regulations would be enforced in an economy that is highly dependent on tourism, even though enforced building standards tend to make a positive impact on adaptation and wider risk reduction (Spence, 2004).

Adaptation Taxes or Levies

Taxation or levy systems could generate additional funds to finance adaptation measures. At the moment, no such specific adaptation taxes or levies for the tourism industry are implemented in any of the islands represented by interviewees. Although many SIDS have departure taxes/tolls or 'green' fees for tourists, none directly addresses or funds adaptation. MA, PNG, and SI indicated that they are very cautious about creating an extra burden (or something perceived as being a burden) on the increasingly competitive tourism enterprises operating in their countries. WT stated, "generally speaking, taxing tourism is not helpful; tourism is enormously price-sensitive". Apart from these concerns towards regulation, two interviewees said that fiscal mechanisms such as taxes or levies would be the most efficient way to raise funds for adaptation (TO1, TO2). Governments could also use funding from taxes independently for adaptation interventions.

This autonomous management of funding was, on the other hand, a big concern raised by the industry (TO1, TO2, WT). They mentioned that taxes in many cases were used to "fix holes in national budgets" and they were afraid that adaptation taxes could be misused or even disappear in other channels. Therefore, a clear trust issue emerged and any taxation system would need to be transparent and carefully designed so as not to trigger negative consequences, or perceived negative consequences, for the sector. Transparency International's (2016) corruption perceptions index gives wide-ranging results for tourism-dependent SIDS (e.g., Barbados is tied with the USA at #16, but Dominican Republic is ranked at #103), although most SIDS are not listed. Fiji, for instance, is not listed and has a high rate of corruption perceptions (Pathak, Naz, Rahman, Smith, & Nayan Agarwal, 2009).

Adaptation Funds

Adaptation funds are funds that are created to pool finance to incentivize action or invest in adaptation measures, projects, or programmes. Adaptation funds could be set up at any governance level: global, regional, national, or local. Most interviewees rated adaptation funds as being a feasible mechanism (UNW, UN, MA, SL, SI, TO1). All industry representatives preferred adaptation funds as a way to finance adaptation when compared to taxes or levies (TO1, TO2, WT). Regional, national, or local funds were perceived to be better than international ones due to fewer organisational challenges and the possibility of reconciling differing interests.

Regional and local funds could be initiated, sourced, and managed by governments, independent institutions, and/or the private sector (WT). The capital raised was suggested as financing mainly visible adaptation measures, such as building structural defences along the shoreline (ex-post) or rebuilding infrastructure to factor in climate change impacts (ex-ante).

No country was identified as having a tourism industry that implemented a climate adaptation fund as part of its funding structure. However, the Caribbean region implemented the Caribbean Catastrophe Risk Insurance Facility (CCRIF), which could be interpreted as functioning in a comparable manner to an ex-post orientated adaptation fund (CCRIF, 2014). PNG, SI, and MA were all positive about implementing such funds in their region and currently plan to set up a national climate change fund that partly finances adaptation. Nonetheless, they were cautious about involving the tourism industry as a source of funding (MA, SI), as in their view, doing so could potentially discourage the industry from investing. This reaction once more demonstrated the dependency (or assumed dependency) of SIDS on the tourism sector, along with the assumption that requests or demands for adaptation financing will limit investment in tourism, thereby limiting the governments' negotiating power. As potential countermeasures, increasing a fund's transparency and possibly involving the tourism sector as managing board members seemed to raise the industries' acceptance of such a mechanism (TO2, WT).

Water Use Management

Another potential mechanism to fund CCA efforts in the tourism industry is sustainable water management practices for both demand and supply, including the treatment of wastewater to avoid health impacts and the reduction of overall water use. Sustainable water management practices are always needed, given how excessive water use can be in the tourism industry (Garcia & Servera, 2003); but such measures can only be regarded as adaptive in nature, particularly in destinations where climate change impacts the availability of fresh water or the negative consequences of untreated wastewater. These trends are expected in most SIDS due to saltwater intrusion driven by sea-level rise (IPCC, 2014b; UNWTO et al., 2008). Some SIDS already import fresh water using tanker ships, including Fiji, Tonga, Bahamas, Antigua and Barbuda, and Nauru (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2012). This problem is further reinforced by tourism development trends towards higher fresh water use, leading to the situation wherein "tourism development in many areas of the world may become less sustainable or no longer feasible" (Gössling et al., 2012, p. 13; Charara, Cashman, Bonnell, & Gehr, 2011; Bishop, 2010).

Apart from the constraint of water availability for tourism, poor water quality and media coverage of water issues can create image problems for destinations (Hall, 2010; Hall & Stoffels, 2006), implying a need for tourism to engage more proactively in water management (van der Velde, Green, Vanclooster, & Clothier, 2007; Hall & Härkönen, 2006). A positive aspect of improved water management is the potential to simultaneously reduce costs since "it seems beyond doubt that most of the measures that can reduce water use are economical" (Gössling et al., 2012, p. 13). The UNWTO representative stated that this framing of the environmental problem in economic terms was in his experience the key strategy for convincing the private sector to act in a developing country context.

Risk Transfer Mechanisms

The most common risk sharing and transfer mechanisms in the tourism sector are insurance-related schemes, in which investments could easily be tracked. These mechanisms usually "manage risks that would be too large for companies or individuals to cover on their own" (Warner et al., 2013, p. 11). Particularly in the context of climate change, they could play a key role for tourism firms in managing risk and enabling investments and operations despite uncertainties under climate change.

While insurance can raise awareness about risk management and adaptation, "climate change may bring some residual risks which cannot be transferred to the insurance market cost-effectively" (Warner et al., 2013, p. 13) and might discourage adaptation. UNFCCC (2012) estimated that for countries which are highly exposed to slow-onset climatic processes, such as sea-level rise, traditional risk transfer approaches could be unsuitable. This is the case if two main preconditions for traditional insurance schemes to work are not fully applicable (Warner et al., 2013, p. 14): "the unpredictability of a specific event and ability to spread risk over time and regions, between individuals/entities".

An alternative investigated and piloted scheme is weather-index based insurance products (Munich Climate Insurance Initiatives [MCII], 2014). In contrast to traditional insurance schemes, the weather-index based payout allows an immediate payout after a disaster, thus payouts are not bound to the value of the asset, but insurance credits can be purchased and payouts are related to the amount of credits which an enterprise holds. Most of the country representatives had already heard about such schemes, in contrast to the industry representatives, although the interviewees stated that majority of the bigger tourism enterprises in SIDS are already insured.

Discussion

Based on the mechanisms identified by the interviewees and literature, this section discusses the influence of interests and operational scales on the feasibility of implementing the mechanisms.

The results imply that the tourism industry is more likely to support some mechanisms than others, mainly emerging from the tour operator representatives stating that they cannot use adaptation projects as effective marketing tools. Considering the possible drivers for the private sector to invest in its own CCA (Pauw & Scholz, 2012), the industry interviewees indicated interest in protecting their business from negative impacts through risk transfer mechanisms and exploiting beneficial opportunities through water management. Corporate social responsibility was rarely mentioned and could not be depicted directly by any single mechanism, whereas water efficiency could possibly be used for marketing purposes.

While the responses indicate that industry representatives have a limited understanding of adaptation and its benefits, this does not translate to invalid views. Rather, an improved understanding could yield a higher and more positive perspective and motivation for the tourism industry to fund its own CCA. Informational programs from SIDS governments might convince the tourism industry to be more involved in financing its CCA—or could at least seed the ideas for the tourism industry to start engaging in dialogue with governments.

The other identified mechanisms appear to have fewer direct positive rewards for the industry, so the interviewees intimated reluctance to incur the additional costs assumed to be required, corroborating earlier findings from Fiji (Becken, 2005). Similarly, Sovacool, Linnér, and Klein (2017) document limited results from an adaptation fund for Maldives and Vanuatu, amongst other countries, raising the question of why the tourism industry should contribute to such a fund. Thus, the mechanisms can be clustered according to the perceived interests of government and of the private sector in initiating the mechanism for increasing adaptation financing (Figure 1). SIDS governments would need to play a significant role in initiating mechanisms, but then they might give in to tourism industry lobbying against the mechanisms based on perceived costs.

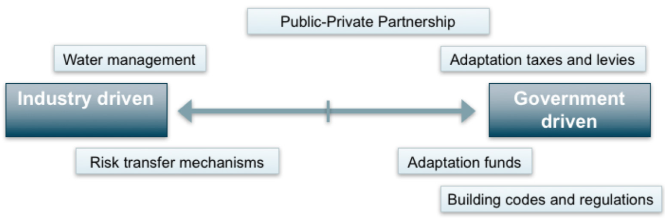


Figure 1. Categorisation of mechanisms on CCA financing according to the likely initiator

In this context, the differing operational scales and abilities of stakeholders for dealing with climate change should be considered for a clearer picture of the feasibility of implementing certain mechanisms. Interest in adaptation engagement tends to be lower where adaptive capacities are higher and vice versa (Hess, Pauw, & Papyrakis, 2015), suggesting that the industry might favour certain mechanisms precisely because these stakeholders feel that their adaptive capacities are low, so they need to act. Industry stakeholders who are bound to a specific location, such as hotels, beach owners, and protected area tour operators, tend to be less flexible for relocating their operations, if it is even possible, thereby increasing exposure to risks and potentially favouring prompt adaptation action.

SIDS governments should therefore consider factoring in industry operational scale and interests when deciding how to act on financing tourism industry adaptation. This conclusion is supported by Pauw, Klein, Vellinga, and Biermann (2016) who detailed specific limitations for monitoring and reporting private sector financing for climate adaptation. In fact, the results demonstrate that, whereas multinational tour operators tend to have the highest flexibility for selecting and adjusting mechanisms, their willingness to finance adaptation appears to be low. Conversely, the tendency is the opposite for more locally bound stakeholders. Nonetheless, businesses looking towards the long-term, or businesses seeking government direction because the industry's adaptability is low, might be supportive of government interventions.

Conclusion and Recommendations

This exploratory study showed that several promising mechanisms exist for involving the tourism industry in financing its own CCA in SIDS as viewed by the interview respondents. The industry representatives perceived that the willingness to become involved may vary significantly due to differences in the industry's knowledge of, ability in, and interest regarding CCA as well as their operational scale. On a destination or regional scale, adaptation funds, risk transfer mechanisms, and PPPs proved to be particularly promising. Overall, private adaptation financing initiatives were widely acknowledged by the interviewees as being preferable, as they are seen to be more transparent than taxes or levies, while the industry could hold positions on the fund's management board.

Despite the overall potential, in-depth interviews and literature review pointed to a number of challenges in involving the tourism industry in financing its own CCA in SIDS. Varying incentive structures and the price sensitivity of the sector suggest that government frameworks would be needed to effect substantive action. Moreover, this study showed that approaching the sector to support adaptation financing should likely be based on demonstrating cost-effective interventions or possible costly threats. Such an approach typically increases the chances of gaining the attention of firms, raising awareness, and creating a knowledge base on which the necessity of supporting adaptation action could be communicated.

Further research should be undertaken to supplement these exploratory findings for each identified mechanism and for possible interactions amongst them. Building on the findings of the study, follow-up stakeholder group interviews in SIDS could reveal how stakeholder interdependencies and power dynamics could further shape the potential of involving the SIDS tourism industry in adaptation financing. Quantitative surveys alongside qualitative interviews covering more stakeholders could be undertaken to determine the wider tourism industry stakeholders' perceptions of mandatory and voluntary involvement in adaptation financing. The data would contribute to scoping the practicality and feasibility of implementing certain mechanisms in specific SIDS contexts. The opportunity also exists to further test assumptions of stakeholder theory in SIDS contexts, to indicate whether or not the theory would need to be modified to account for the small, closely knit populations. Thus, continuing to examine tourism industry financing of CCA in SIDS can make both theoretical and empirical contributions to the literature.

References

Ackerman, F., & Stanton, E. A. (2013). *Climate economics: the state of the art*. London ; New York: Routledge.

Agrawala, S., Carraro, M., Kingsmill, N., Lanzi, E., Mullan, M., & Prudent-Richard, G. (2011). *Private Sector Engagement in Adaptation to Climate Change* (OECD Environment Working Papers No. 39). Organisation for Economic Co-operation and Development.

Allison, W. R. (1996). Snorkeler damage to reef corals in the Maldive Islands. *Coral Reefs, 15*(4), 215–218. https://doi.org/10.1007/BF01787454

Atteridge, A. (2011). *Will Private Finance Support Climate Change Adaptation in Developing Countries?: Historical*

Investment Patterns as a Window on Future Private Climate Finance (Working Paper 2011). Stockholm: Stockholm Environment Institute. Retrieved from http://www.sei-international.org/mediamanager/documents/Publications/SEI-WorkingPaper-Atteridge-WillPrivateFinanceSupportClimateChangeAdaptationInDevelopingCountries-2011.pdf

Babbie, E. R. (2010). *The practice of social research* (12th ed). Belmont, California: Wadsworth Cengage.

Becken, S. (2005). Harmonising climate change adaptation and mitigation: The case of tourist resorts in Fiji. *Global Environmental Change, 15*(4), 381–393. https://doi.org/10.1016/j.gloenvcha.2005.08.001

Becken, S., & Hay, J. E. (2007). *Tourism and climate change risks and opportunities.* Clevedon, UK; Buffalo: Channel View Publications. Retrieved from http://site.ebrary.com/id/10189013

Becken, S., & Hay, J. E. (2012). *Climate change and tourism: from policy to practice*. New York: Routledge.

Becken, S., Hay, J., & Espiner, S. (2010). The risk of climate change for tourism in the Maldives. In J. Carlsen & R. Butler (Eds.), *Island tourism: towards a sustainable perspective* (pp. 72–84). Wallingford, Oxfordshire, [England] ; Cambridge, MA: CABI.

Belle, N., & Bramwell, B. (2005). Climate Change and Small Island Tourism: Policy Maker and Industry Perspectives in Barbados. *Journal of Travel Research, 44*(1), 32–41. https://doi.org/10.1177/0047287505276589

Bishop, M. L. (2010). Tourism as a Small-State Development Strategy Pier Pressure In The Eastern Caribbean? *Progress in Development Studies, 10*(2), 99–114. https://doi.org/10.1177/146499340901000201

Bradshaw, B., Dolan, H., & Smit, B. (2004). Farm-Level Adaptation to Climatic Variability and Change: Crop Diversification in the Canadian Prairies. *Climatic Change, 67*(1), 119–141. https://doi.org/10.1007/s10584-004-0710-z

Brau, R., Liberto, D., & Pigliaru, F. (2011). Tourism and Development: A recent phenomenon built on old (institutional) roots? *WORLD ECONOMY, 34*(3), 444–472. https://doi.org/10.1111/j.1467-9701.2010.01320.x

Brown, J., Stadelmann, M., Wang, D., Boni, L., Jachnik, R., & Kato, T. (2015). *Estimating mobilized private finance for adaptation: Exploring data and methods.* Climate Policy Initiative (CPI).

Bryman, A. (2012). *Social research methods* (4th ed). Oxford ; New York: Oxford University Press.

Buchner, B., Herve-Mignucci, M., Trabacchi, C., Wilkinson, J., Stadelmann, M., Boyd, R., … Micale, V. (2013). *Global Landscape of Climate Finance 2013*. San Francisco: Climate Policy Initiative. Retrieved from http://climatepolicyinitiative.org/wp-content/uploads/2013/10/The-Global-Landscape-of-Climate-Finance-2013.pdf

Buchner, B., Trabacchi, C., Mazza, F., Abramskiehn, D., & Wang, D. (2015). *Global Landscape of Climate Finance 2015*. San Francisco: Climate Policy Initiative.

Caribbean Catastrophe Risk Insurance Facility. (2014). About us. Retrieved 18 July 2014, from http://www.ccrif.org/content/about-us

Chambwera, M., Njewa, E. D., & Loga, D. (n.d.). *The International Air Passenger Adaptation Levy: Opportunity or risk for Least Developed Countries?* (LDC paper series). International Institute for Environment and Development and European Capacity Building Initiative.

Charara, N., Cashman, A., Bonnell, R., & Gehr, R. (2011). Water use efficiency in the hotel sector of Barbados. *Journal of Sustainable Tourism, 19*(2), 231–245. https://doi.org/10.1080/09669582.2010.502577

Christiansen, L., Ray, A. D., Smith, J. B., & Haites, E. (2012). *Accessing international funding for climate change adaptation: a guidebook for developing countries.* Rosklide: UNEP Risø Centre on Energy, Climate and Sustainable Development.

Central Intelligence Agency. (2014). The World Factbook: Australia-Oceania: Palau. Retrieved 23 June 2014, from https://www.cia.gov/library/publications/the-world-factbook/geos/ps.html

Connell, J. (2013). *Islands at risk?: environments, economies and contemporary change.* Cheltenham: Edward Elgar.

Croes, R. R. (2006). A paradigm shift to a new strategy for small island economies: Embracing demand side economics for value enhancement and long term economic stability. *Tourism Management, 27*(3), 453–465. https://doi.org/10.1016/j.tourman.2004.12.003

Dzebo, A., & Pauw, P. (2014). It's time to look beyond the UN's $100bn climate finance target. Retrieved 19 May 2014, from http://www.rtcc.org/2014/05/01/its-time-to-look-beyond-the-uns-100nn-climate-finance-target/

Freeman, R. E. (1984). *Strategic management: a Stakeholder Approach*. Boston: Pitman.

Gaillard, J. (2007). Resilience of traditional societies in facing natural hazards. Disaster Prevention and Management: *An International Journal, 16*(4), 522–544. https://doi.org/10.1108/09653560710817011

Garcia, C., & Servera, J. (2003). Impacts of Tourism Development on Water Demand and Beach Degradation on the Island of

Mallorca (Spain). *Geografiska Annaler, Series A: Physical Geography, 85*(3–4), 287–300. https://doi.org/10.1111/j.0435-3676.2003.00206.x

Gössling, S., Bredberg, M., Randow, A., Sandstrom, E., & Svensson, P. (2006). Tourist Perceptions of Climate Change: A Study of International Tourists in Zanzibar. *Current Issues in Tourism, 9*(4), 419–435. https://doi.org/10.2167/cit265.0

Gössling, S., Peeters, P., Hall, C. M., Ceron, J.-P., Dubois, G., Lehmann, L. V., & Scott, D. (2012). Tourism and water use: Supply, demand, and security. An international review. *Tourism Management, 33*(1), 1–15. https://doi.org/10.1016/j.tourman.2011.03.015

Graci, S., & Dodds, R. (2010). *Sustainable tourism in island destinations*. London ; Washington, DC: Earthscan.

Gray, B. (1991). Collaborative Alliances: Moving from Practice to Theory. *The Journal of Applied Behavioral Science, 27*(1), 3–22. https://doi.org/10.1177/0021886391271001

Grimsey, D., & Lewis, M. (2004). *Public private partnerships the worldwide revolution in infrastructure provision and project finance*. Cheltenham; Northampton, MA: Edward Elgar. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=128391

Haigh, N., & Griffiths, A. (2009). The natural environment as a primary stakeholder: the case of climate change. *Business Strategy and the Environment, 18*(6), 347–359. https://doi.org/10.1002/bse.602

Hall, C. M. (2010). Crisis events in tourism: subjects of crisis in tourism. *Current Issues in Tourism, 13*(5), 401–417. https://doi.org/10.1080/13683500.2010.491900

Hall, C. M., & Härkönen, T. (2006). *Lake Tourism: An Integrated Approach to Lacustrine Tourism Systems*. Channel View Publications.

Hall, C. M., & Stoffels, M. (2006). Lake Tourism in New Zealand: Sustainable Management Issues. In C. M. Hall & T. Härkönen (Eds.), *Lake Tourism: An Integrated Approach to Lacustrine Tourism Systems*. Channel View Publications.

Hess, J. S., Pauw, P., & Papyrakis, E. (2015). *Can the tourism industry contribute to international adaptation finance?* (Briefing Paper No. 2/2015). Bonn: German Development Institute (GDI-DIE). Retrieved from http://www.die-gdi.de/briefing-paper/article/can-the-tourism-industry-contribute-to-international-adaptation-finance/

Hodge, G. A. (2004). The risky business of public-private partnerships. *Australian Journal of Public Administration, 63*(4), 37–49. https://doi.org/10.1111/j.1467-8500.2004.00400.x

Hodge, G. A., & Greve, C. (2007). Public–Private Partnerships: An International Performance Review. *Public Administration Review, 67*(3), 545–558. https://doi.org/10.1111/j.1540-6210.2007.00736.x

Huxham, C., & Vangen, S. (2002). In S. P. Osborne (Ed.), *Public Management: Critical Perspectives* (pp. 273–292). Taylor & Francis.

Intergovernmental Panel on Climate Change. (2014a). Summary for Policymakers. In *Climate Change 2014: Working Group II Contribution to the IPCC Fifth Assessment Report*. Cambridge: Cambridge University Press. Retrieved from http://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf

Intergovernmental Panel on Climate Change. (2014b). *Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]* (p. 151). Geneva: International Pannel on Climate Change.

Juhasz, A., Ho, E., Bender, E., & Fong, P. (2010). Does use of tropical beaches by tourists and island residents result in damage to fringing coral reefs? A case study in Moorea French Polynesia. *Marine Pollution Bulletin, 60*(12), 2251–2256. https://doi.org/10.1016/j.marpolbul.2010.08.011

Kolk, A., & Pinkse, J. (2005). Business Responses to Climate Change: Identifying Emergent Strategies. *California Management Review, 47*(3), 6–20. https://doi.org/10.2307/41166304

Lewis, J. (1999). *Development in disaster-prone places: studies of vulnerability.* London: Intermediate Technology.

Liamputtong, P. (2013). *Qualitative research methods* (Fourth edition). Australia: Oxford University Press.

Mahon, R., Becken, S., & Rennie, H. G. (2013). *Evaluating the business case for investment in the resilience of the tourism sector of small island developing states.* Christchurch: Lincoln University (Canterbury N.Z.); Lincoln University. Retrieved from http://researcharchive.lincoln.ac.nz/dspace/bitstream/10182/5300/3/LEaP_rr_32.pdf

Mansfeld, Y., & Korman, T. (2015). Between war and peace: conflict heritage tourism along three Israeli border areas. *Tourism Geographies, 17*(3), 437–460. https://doi.org/10.1080/14616688.2015.1036916

Méheux, K., & Parker, E. (2006). Tourist Sector Perceptions of the Natural Hazards in a Small Island Developing State: A Prliminary Study and Recommendations for an Awareness Strategy in Vanuatu. *Macquire University*. Retrieved from http://www.grif.umontreal.ca/pages/papers2004/Paper%20-%20Meheux%20K,%20Parker%20E.pdf

Munich Climate Insurance Initiative. (2014). MCII - Mission & Targets. Retrieved 16 July 2014, from http://www.climate-insurance.org/front_content.php?idcat=876

Müller, B. (2008). *International Air Passenger Adaptation Levy (IAPAL): A proposal by the Group of Least Developed Countries (LDCs) within the framework of the Bali Action Plan* (Policy Brief). Oxford: European Capacity Building Initiative.

Narayan, P. K., Narayan, S., Prasad, A., & Prasad, B. C. (2010). Tourism and economic growth: a panel data analysis for Pacific Island countries. *Tourism Economics, 16*(1), 169–183. https://doi.org/10.5367/000000010790872006

Nurse, L. A., McLean, R. F., Agard, J., Bringuglio, L. P., Duvat-Magnan, V., Pelesikoti, N., … Webb, A. (2014). Small islands. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. In V. R. Barros, C. B. Field, D. J. Dokken, K. J. Mastrandrea, T. E. Mach, M. Bilir, … L. L. White (Eds.), *Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1613–1654). Cambridge: Cambridge University Press.

Orts, E. W., & Strudler, A. (2002). The Ethical and Environmental Limits of Stakeholder Theory. *Business Ethics Quarterly, 12*(2), 215–233. https://doi.org/10.2307/3857811

Osborne, S., & Murray, V. (2000). Understanding the process of public-priavte partnerships. In S. Osborne (Ed.), P*ublic-Private Partnerships: Theory and Practice in International Perspective* (pp. 70–83).

Osorio, S. G., & Best, G. (2015). A Case Study on Culture Brokers and Their Role in Tourism Management in the Indigenous Community of Taquile Island in Puno, Peru: Role of Culture Brokers in the Indigenous Community of Taquile in Peru. *International Journal of Tourism Research, 17*(4), 347–355. https://doi.org/10.1002/jtr.1992

Pathak, R. D., Naz, R., Rahman, M. H., Smith, R. F. I., & Nayan Agarwal, K. (2009). E-Governance to Cut Corruption in Public Service Delivery: A Case Study of Fiji. *International Journal of Public Administration, 32*(5), 415–437. https://doi.org/10.1080/01900690902799482

Pauw, P., & Pegels, A. (2013). Private sector engagement in climate change adaptation in least developed countries: an exploration. *Climate and Development, 5*(4), 257–267. https://doi.org/10.1080/17565529.2013.826130

Pauw, P., & Scholz, I. (2012). *Finanzierung der Klimaanpassung in armen Ländern – Sache des Privatsektors?: Deutsches Institut für Entwicklungspolitik* (No. Die aktuelle Kollumne vom 26.11.2012). Bonn: German Development Institute (GDI-DIE). Retrieved from http://www.die-gdi.de/die-aktuelle-kolumne/article/finanzierung-der-klimaanpassung-in-armen-laendern-sache-des-privatsektors/

Pauw, W. P. (2015). Not a panacea: private-sector engagement in adaptation and adaptation finance in developing countries. *Climate Policy, 15*(5), 583–603. https://doi.org/10.1080/14693062.2014.953906

Pauw, W. P., Klein, R. J. T., Vellinga, P., & Biermann, F. (2016). Private finance for adaptation: do private realities meet public ambitions? *Climatic Change, 134*(4), 489–503. https://doi.org/10.1007/s10584-015-1539-3

Persson, Å., Klein, R. J. T., Siebert, C., Atteridge, A., Müller, B., Hoffmaister, J., … Takama, T. (2009). *Adaptation finance under a Copenhagen agreed outcome*. Stockholm: Stockholm Environment Institute.

Phillips, R. A., & Reichart, J. (2000). The Environment as a Stakeholder? A Fairness-Based Approach. *Journal of Business Ethics, 23*(2), 185–197. https://doi.org/10.1023/A:1006041929249

Phillips, R., Freeman, R. E., & Wicks, A. C. (2003). What Stakeholder Theory is Not. *Business Ethics Quarterly, 13*(4), 479–502. https://doi.org/10.5840/beq200313434

Qiu, Z., & Prato, T. (2012). Economic feasibility of adapting crop enterprises to future climate change: a case study of flexible scheduling and irrigation for representative farms in Flathead Valley, Montana, USA. *Mitigation and Adaptation Strategies for Global Change, 17*(3), 223–242. https://doi.org/10.1007/s11027-011-9322-x

Roehrich, J. K., Lewis, M. A., & George, G. (2014). Are public–private partnerships a healthy option? A systematic literature review. *Social Science & Medicine, 113*, 110–119. https://doi.org/10.1016/j.socscimed.2014.03.037

Rosenau, P. V. (2000). *Public-private policy partnerships*. Cambridge, Mass: MIT Press.

Sanger, T., & Crawley, C. (2009). The Problem with Public-Private Partnerships: Economic crisis exposes the high costs and risks of P3s. Retrieved from https://www.policyalternatives.ca/publications/monitor/problem-public-private-partnerships

Schelling, T. C. (2007). Climate change: The uncertainties, the certainties and what they imply about action. *The Economists' Voice 4.3. Colombia University Press*. Retrieved from http://www.degruyter.com/dg/viewarticle.fullcontentlink:pdfeventlink/$002fj$002fev.2007.4.3$002fev.2007.4.3.1276$002fev.2007.4.3.1276.pdf?t:ac=j$002fev.2007.4.3$002fev.2007.4.3.1276$002fev.2007.4.3.1276.xml

Scheyvens, R., & Momsen, J. H. (2008). Tourism and Poverty Reduction: Issues for Small Island States. *Tourism Geographies, 10*(1), 22–41. https://doi.org/10.1080/14616680701825115

Scott, D., & Becken, S. (2010). Adapting to climate change and climate policy: progress, problems and potentials. *Journal of Sustainable Tourism, 18*(3), 283–295. https://doi.org/10.1080/09669581003668540

Scott, D., Gössling, S., & Hall, C. M. (2012). International tourism and climate change. Wiley Interdisciplinary Reviews: *Climate Change, 3*(3), 213–232. https://doi.org/10.1002/wcc.165

Scott, D., Hall, C. M., & Gössling, S. (2016). A report on the Paris Climate Change Agreement and its implications for tourism: why we will always have Paris. *Journal of Sustainable Tourism, 24*(7), 933–948. https://doi.org/10.1080/09669582.2016.1187623

Shakeela, A., & Becken, S. (2015). Understanding tourism leaders' perceptions of risks from climate change: an assessment of policy-making processes in the Maldives using the social amplification of risk framework (SARF). *Journal of Sustainable Tourism, 23*(1), 65–84. https://doi.org/10.1080/09669582.2014.918135

Sovacool, B. K. (2012). Perceptions of climate change risks and resilient island planning in the Maldives. *Mitigation and Adaptation Strategies for Global Change, 17*(7), 731–752. https://doi.org/10.1007/s11027-011-9341-7

Sovacool, B. K., Linnér, B.-O., & Klein, R. J. T. (2017). Climate change adaptation and the Least Developed Countries Fund (LDCF): Qualitative insights from policy implementation in the Asia-Pacific. *Climatic Change, 140*(2), 209–226. https://doi.org/10.1007/s10584-016-1839-2

Spence, R. (2004). Risk and regulation: can improved government action reduce the impacts of natural disasters? *Building Research & Information, 32*(5), 391–402. https://doi.org/10.1080/0961321042000221043

Starik, M. (1995). Should trees have managerial standing? Toward stakeholder status for non-human nature. *Journal of Business Ethics, 14*(3), 207–217. https://doi.org/10.1007/BF00881435

Surminski, S. (2013). Private-sector adaptation to climate risk. *Nature Climate Change, 3*(11), 943–945. https://doi.org/10.1038/nclimate2040

Transparency International. (2016). Corruption Perceptions Index 2015. Retrieved 10 November 2016, from http://www.transparency.org/cpi2015#results-table

Turton, S., Dickson, T., Hadwen, W., Jorgensen, B., Pham, T., Simmons, D., … Wilson, R. (2010). Developing an approach for tourism climate change assessment: evidence from four contrasting Australian case studies. *Journal of Sustainable Tourism, 18*(3), 429–447. https://doi.org/10.1080/09669581003639814

United Nations Environmental Programme. (2016). The Adaptation Finance Gap Report 2016. Nairobi: United Nations Environment Programme (UNEP).

United Nations Educational, Scientific and Cultural Organization. (2012). *Knowledge Base: The United Nations World Water Development Report 4* (World Water Development Report No. 4). Paris: United Nations Educational, Scientific and Cultural Organization.

United Nations Framework Convention on Climate Change. (2007). *Vulnerability and Adaptation to Climate Change in Small Island Developing States* (Background paper for the expert meeting on adaptation for small island developing states). Bonn: United Nations Framework Convention on Climate Change.

United Nations Framework Convention on Climate Change. (2012). *Slow onset events* (No. Technical Paper). Bonn: United Nations Framework Convention on Climate Change. Retrieved from http://unfccc.int/resource/docs/2012/tp/07.pdf

United Nations Framework Convention on Climate Change. (2014). Private Sector Initiative Actions on Aaptation: Improving customer confidence in attractiveness of destination. Retrieved 12 December 2016, from http://unfccc.int/files/adaptation/nairobi_work_programme/private_sector_initiative/application/pdf/apple_vacations_et_at.pdf

United Nations Framework Convention on Climate Change. (2015). Paris agreement. UNFCCC. Retrieved from http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

United Nations Framework Convention on Climate Change. (2016). Private Sector Initiative (PSI) - database of actions on adaptation. Retrieved 12 December 2016, from http://unfccc.int/adaptation/workstreams/nairobi_work_programme/items/4623.php

United Nations World Tourism Organization. (2012). *Challenges and Opportunities for Tourism Development in Small Island Developing States*. Madrid: United Nations World Tourism Organization.

United Nations World Tourism Organization. (2015). *Affiliate Members Global Reports, Volume eleven - Public-Private Partnerships: Tourism Development*. Madrid: World Tourism Organization (UNWTO).

United Nations World Tourism Organization. (2016). *UNWTO annual report 2015*. Madrid: United Nations World Tourism Organization.

United Nations World Tourism Organization, United Nations Environmental Programme, & World Meteorological Organization. (2008). *Climate change and tourism: responding to global challenges.* Madrid; Paris: World Tourism Organization ; United Nations Environment

Programme ; World Metereological Organization.

van der Velde, M., Green, S. R., Vanclooster, M., & Clothier, B. E. (2007). Sustainable development in small island developing states: Agricultural intensification, economic development, and freshwater resources management on the coral atoll of Tongatapu. *Ecological Economics, 61*(2–3), 456–468. https://doi.org/10.1016/j.ecolecon.2006.03.017

Warner, K., Yuza, K., Zissener, M., Gille, M., Voss, J., & Wanczeck. (2013). *Innovative Insurance Solutions for Climate Change: How to integrate climate risk insurance into a comprehensive climate risk management approach.* Bonn: United Nations Univeristy Institute for Environment and Human Security (UNU-EHS).

Wong, E. P. Y., de Lacy, T., & Jiang, M. (2012). Climate change adaptation in tourism in the South Pacific — Potential contribution of public–private partnerships. *Tourism Management Perspectives, 4*, 136–144. https://doi.org/10.1016/j.tmp.2012.08.001

Wright, N. (2013). *Small Island Developing Stats, disaster risk management, disaster risk reduction, climate change adaptation and tourism* (Background Paper prepared for the Global Assessment Report on Disaster Risk Reduction 2013). Geneva: United Nations Office for Disaster Risk Reduction.

World Travel and Tourism Council. (2016a). *Travel & Tourism: Economic Impact 2016: Fiji.* London: The World Travel and Tourism Council. Retrieved from http://www.wttc.org/-/media/files/reports/economic-impact-research/countries-2016/fiji2016.pdf

World Travel and Tourism Council. (2016b). *Travel & Tourism: Economic Impact 2016: Vanuatu*. London: The World Travel and Tourism Council. Retrieved from https://www.wttc.org/-/media/files/reports/economic%20impact%20research/countries%202015/vanuatu2015.pdf

Annex 545

H. H. Huang et al., “The impact of climate risk on firm performance and financing choices: An international comparison”, *Journal of International Business Studies,* 2017

Journal of International Business Studies (2017)

www.jibs.net

The impact of climate risk on firm performance and financing choices: An international comparison

Henry He Huang[1], Joseph Kerstein[1] and Chong Wang[2]

[1] *Sy Syms School of Business, Yeshiva University, New York, NY 10033, USA;* [2] *School of Accounting and Finance, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong*

Correspondence:
HH Huang, Sy Syms School of Business, Yeshiva University, New York, NY 10033, USA
e-mail: henry.huang@yu.edu

Abstract

Increasingly adverse climatic conditions have created greater systematic risk for companies throughout the global economy. Few studies have directly examined the consequences of climate-related risk on financing choices by publicly listed firms across the globe. We attempt to do so using the Global Climate Risk Index compiled and published by Germanwatch (Kreft & Eckstein, 2014), which captures at the country level the extent of losses from extreme weather events. As expected, we find the likelihood of loss from major storms, flooding, heat waves, etc. to be associated with lower and more volatile earnings and cash flows. Consistent with policies that attempt to moderate such effects, we show that firms located in countries characterized by more severe weather are likelier to hold more cash so as to build financial slack and thereby organizational resilience to climatic threats. Those firms also tend to have less short-term debt but more long-term debt, and to be less likely to distribute cash dividends. In addition, we find that certain industries are less vulnerable to extreme weather and so face less climate-related risk. Our results are robust to using an instrumental variable approach, a propensity-score-matched sample, and path analysis, and remain unchanged when we consider an alternative measure of climate risk. Finally, our conclusions are invariant to the timing of financial crises that can affect different countries at different times.
Journal of International Business Studies (2017).
doi:10.1057/s41267-017-0125-5

Keywords: climate risk; extreme weather; earnings volatility; financing choice

Received: 24 July 2016
Revised: 11 September 2017
Accepted: 14 October 2017

INTRODUCTION

The effect of climate on economic performance has long been recognized and documented (e.g., Dell, Jones, & Olken, 2014; Gallup, Sachs, & Mellinger, 1999; Nordhaus, 2006). Studies have generally focused on the economic impact of climatic events on geographic units (countries and municipalities). Concern about worldwide changes in climate has also led to an examination of the impact of the environment on firm valuation (e.g., Beatty & Shimshack, 2010; Chava, 2014; Konar & Cohen, 2001; Matsumura, Prakash, & Vera-Munoz, 2014). Those studies generally consider regulatory and environmental risks associated with carbon dioxide emissions and other pollutants. We are not aware of any work that directly examines the effect of climate on publicly listed firms. Moreover, few studies have addressed whether and to what extent managers of public firms worldwide weigh the risk of extreme weather shocks when formulating financial policies.[1] Yet managers are likely to be influenced by *climate risk*, that is, losses from major weather events such as storms, floods, and heat waves, because they cannot obtain full insurance coverage against it.[2]

We use a cross-country empirical setting to examine the effect of climate risk on the financing and performance of publicly traded firms around the globe. Our proxy for climate risk is the Global Climate Risk Index (hereafter CRI) compiled and published by the non-profit, non-governmental organization Germanwatch (Kreft & Eckstein, 2014), which provides a quantified measure by country of extreme weather-related economic losses. This measure is also indicative of future extreme weather events (Kreft & Eckstein, 2014). Our study is based on both a long-term CRI score for the years 1993–2012 and seven annual CRI scores for the years 2006–2012. According to Kreft and Eckstein (2014), from 1992 to 2011 extreme weather events led to more than 530,000 casualties and economic losses of over 2.5 trillion USD at purchasing power parity (PPP). There is also anecdotal evidence of significantly negative effects of extreme weather on firm performance. For example, in Hurricane Katrina's aftermath, many chemical firms experienced lower earnings due to surging energy costs and lost production facilities (Reisch, 2005).

Our sample consists of 353,906 firm-years from 55 countries over 20 years from 1993 to 2012. Table 1 gives the distribution of firm-years by country. We control for firm-level factors (e.g., size, age, assets, and growth) and country-level factors (e.g., GDP, GDP growth, and legal environment). As expected, we find that firms in countries with higher climate risk have poorer economic performance as measured by return-on-assets (*ROA*) and cash flows from operations over assets (*CFO*). Moving from the first quartile to the more risky third quartile of the annual CRI score can reduce a firm's *ROA* by 1.8 percentage points. We find also that firms in countries experiencing higher climate risk have more volatile earnings, measured by both accounting earnings and operating cash flows. This is consistent with extreme weather events disrupting business operations and bringing about fluctuations in earnings and operating cash flows.

Next, we examine whether climate risk is anticipated by managers and if it leads them to make changes in financing policies. Diamond (1991) and Bates, Kahle, and Stulz (2009) find that policies on debt and cash holdings are driven by liquidity concerns. We expect and find that firm managers in environments characterized by higher climate risk are concerned about being able to repay their creditors should an extreme weather event occur that inflicts considerable losses and hence rely less on short-term and more on long-term borrowing. We find that they are also likely to hold more cash and to issue lower cash dividends. These results suggest that firms use financing policies to hedge against operating cash flow volatility and illiquidity due to higher climate risk. However, we also find that the effect of climate risk on firm performance varies across industries, as climate risk has a more negative impact on some than on others.

We conduct an array of robustness tests. To mitigate concern about the omission of country-level control variables, we use the instrumental variable approach and continue to find similar results. We also use propensity scores to match observations on firm characteristics. The results remain robust. They are also robust to other factors such as whether or not the firm has climate risk insurance coverage and whether it is a multinational firm. We also test for alternative measures of climate-related risk, for the exclusion of US firms from the sample, and for the inclusion of CRI sub-indicators one at a time.

Our research makes at least two important contributions. To the best of our knowledge, it is the first study on the direct impact of the risk of major weather events on public firm performance in a cross-country setting. We find that firms in countries that face higher climate risk have significantly lower and more volatile earnings and cash flows. Thus, climate risk represents a significant exogenous source of earnings and cash volatility, along with economy, industry, and accounting factors (e.g., uncertainty surrounding accounting estimates) (Dichev & Tang, 2009; Lipe, 1990). This finding is also relevant to the literature on the effect of earnings volatility on firm operations and valuation (e.g., Francis, LaFond, Olsson, & Schipper, 2004; Minton & Schrand, 1999; Ronen & Sadan, 1981; Rountree, Weston, & Allayannis, 2008).

Table 1 Country-level variable measures by country

Country name	Long-term climate risk index (years 1993–2012)	Annual average number of deaths (years 1993–2012)	Annual average number of deaths per 100,000 inhabitants (years 1993–2012)	Annual average losses in US $PPP (years 1993–2012)	Annual average losses per unit GDP in % (years 1993–2012)	Standard deviation of climate risk index (annual)	Annual average LGDP	Annual average GDP growth	LEG_ENV	Number of observations (total 353,906 obs.)
Argentina	−88.5	20.60	0.05	533.90	0.12	12.69	8.98	0.07	2.34	705
Australia	−52.2	46.95	0.23	1702.00	0.24	15.03	10.46	0.11	2.57	15,063
Austria	−61.8	26.90	0.33	382.90	0.15	25.36	10.41	0.04	2.22	1253
Bangladesh	−19.7	816.40	0.56	1833.00	1.16	18.69	6.40	0.10	0.19	179
Belgium	−71.5	86.25	0.82	93.55	0.03	12.75	10.39	0.05	2.16	1552
Brazil	−87	154.00	0.09	761.40	0.04	30.46	8.61	0.09	2.22	3483
Bulgaria	−87	7.30	0.09	142.40	0.16	22.58	8.53	0.12	1.66	142
Canada	−102.2	10.90	0.03	861.20	0.08	10.81	10.34	0.07	2.83	12,929
Chile	−106.5	8.60	0.05	132.50	0.07	23.83	8.94	0.09	1.85	1650
China	−42.3	1820.00	0.14	28,927.00	0.49	8.62	7.68	0.17	2.78	25,256
Colombia	−54.2	111.30	0.27	608.10	0.18	23.10	8.18	0.11	1.03	286
Croatia	−59.2	35.15	0.79	86.52	0.13	18.84	9.27	0.06	1.48	261
Czech	−71.2	9.80	0.09	586.40	0.26	21.54	9.22	0.08	0.41	145
Denmark	−115.3	0.80	0.01	215.30	0.13	18.31	10.64	0.04	1.93	1996
Ecuador	−44.3	64.30	0.49	261.70	0.30	32.03	8.24	0.12	2.51	19
Finland	−154.2	0.20	0.00	22.03	0.02	24.27	10.42	0.05	4.08	1856
France	−42.7	959.00	1.59	1623.00	0.09	14.06	10.33	0.04	3.96	9853
Germany	−48	476.30	0.58	2264.00	0.09	11.99	10.37	0.03	2.18	9826
Greece	−84.3	13.50	0.12	249.90	0.10	26.59	9.96	0.05	1.83	2128
Hong Kong	−175.5	0.00	0.00	0.00	0.00	13.17	10.29	0.04	2.86	3117
Hungary	−68	34.75	0.34	173.90	0.11	7.07	9.05	0.08	3.56	239
India	−74.7	246.20	0.12	744.60	0.09	19.81	7.32	0.14	1.02	3662
Indonesia	−38.5	3142.00	0.30	6236.00	0.26	12.34	6.74	0.12	−0.41	25,747
Ireland	−121.2	2.00	0.05	67.44	0.05	17.78	10.44	0.08	2.91	880
Israel	−121.7	4.35	0.07	39.46	0.03	28.54	10.09	0.08	0.98	2145
Italy	−40.7	1003.00	1.73	1564.00	0.10	18.18	10.25	0.04	0.74	3082
Jamaica	−60.5	4.75	0.18	173.00	0.85	22.58	8.36	0.05	1.51	176
Japan	−92	76.25	0.06	1663.00	0.05	15.34	10.52	0.02	3.19	49,376
Lithuania	−80.5	4.50	0.19	59.53	0.19	26.81	9.15	0.12	3.19	244
Malaysia	−85.2	43.70	0.18	163.80	0.06	24.27	8.68	0.10	1.44	11,095
Mexico	−57.7	140.80	0.14	2377.00	0.19	13.85	8.87	0.07	3.09	1534
Morocco	−86.7	31.50	0.11	111.90	0.11	0.00	7.71	0.08	1.93	540
Netherlands	−74.3	84.65	0.53	151.10	0.03	14.03	10.40	0.05	1.31	2506
New Zealand	−83.3	3.40	0.08	224.70	0.23	19.67	10.08	0.09	2.75	1310
Norway	−134.2	1.55	0.03	50.65	0.02	23.96	10.98	0.08	3.24	2560
Pakistan	−31.8	469.90	0.32	2395.00	0.74	21.08	6.66	0.09	2.11	2257
Panama	−95.3	8.80	0.29	16.26	0.06	18.10	8.88	0.13	−0.87	14

Table 1 (*Continued*)

Country name	Long-term climate risk index (years 1993–2012)	Annual average number of deaths (years 1993–2012)	Annual average number of deaths per 100,000 inhabitants (years 1993–2012)	Annual average losses in US $PPP (years 1993–2012)	Annual average losses per unit GDP in % (years 1993–2012)	Standard deviation of climate risk index (annual)	Annual average LGDP	Annual average GDP growth	LEG_ENV	Number of observations (total 353,906 obs.)
Peru	−63.7	109.20	0.42	171.00	0.09	20.00	8.08	0.10	2.74	819
Philippines	−31.2	643.40	0.79	736.30	0.29	15.92	7.26	0.09	2.04	1625
Poland	−66.5	52.20	0.14	859.00	0.16	22.19	9.17	0.09	1.91	3313
Portugal	−37.3	142.60	1.38	404.90	0.20	30.65	9.68	0.04	2.47	756
Russia	−43.5	2962.00	2.04	1727.00	0.08	28.78	8.85	0.18	3.24	1208
Singapore	−168.5	0.10	0.00	2.48	0.00	19.22	10.41	0.10	3.86	7185
Slovakia	−99.7	4.50	0.08	99.88	0.10	15.39	9.11	0.09	1.58	68
Slovenia	−61.2	11.95	0.60	76.69	0.18	16.53	9.76	0.07	0.60	268
South Africa	−85.7	62.25	0.14	212.90	0.05	13.61	8.44	0.08	1.25	3167
Spain	−48.5	704.70	1.67	783.70	0.07	8.73	9.95	0.05	2.10	1913
Sweden	−129.5	1.25	0.01	138.10	0.05	14.69	10.58	0.05	2.17	4979
Switzerland	−48.5	56.15	0.76	389.20	0.15	20.42	10.82	0.05	2.92	3076
Thailand	−31.5	160.30	0.26	5410.00	1.29	23.00	8.06	0.08	3.04	5230
Turkey	−104.2	40.65	0.06	202.60	0.03	19.69	8.89	0.11	2.45	1523
USA	−44.8	486.10	0.17	38,827.00	0.35	8.42	10.55	0.05	4.28	96,841
United Kingdom	−68.7	117.30	0.20	1415.00	0.08	11.03	10.34	0.05	1.89	21,537
Venezuela	−64	68.90	0.27	344.10	0.11	22.29	8.75	0.14	0.66	135
Vietnam	−24	419.70	0.52	1637.00	0.91	10.61	7.16	0.15	3.11	1197

Second, we establish a link between global climate risk and firm financing policies. Prior literature shows that liquidity risk affects firm financial policies on debt, cash holdings, and cash dividend issuance (e.g., Bates et al., 2009; Diamond, 1991; Stulz, 1990; Wang, 2012). For example, holding cash can be a risk management tool against cash fluctuations (Bates et al., 2009). Our findings suggest that firms facing higher climate risk have less short-term but more long-term debt, hold more cash, and distribute lower cash dividends. Our results also suggest that holding more cash to create financial slack is one way for firms to maintain organizational resilience to climate risk.

The remainder of the article is organized as follows. We begin the next section with a literature review and then develop hypotheses. We then explain our climate risk measures and describe our sample. Then, we discuss the methodology, give descriptive statistics, and present our analyses on the effect of climate risk on financial performance, earnings volatility, and cash volatility. We present the results of robustness tests in the penultimate section, and our conclusions in the final section.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Effect of Climate Risk on Financial Performance and Earnings Volatility

It has long been recognized that climate can substantially impact a country's economic performance (Dell et al., 2014). For example, Nordhaus (2006) shows that climate is a key variable in explaining per capita income differences between Africa and wealthier regions of the world. One main measure of climate is temperature. Gallup et al. (1999), Bansal and Ochoa (2012), and Dell, Jones, and Olken (2009) show a negative relationship between temperature and economic performance. Specifically, Gallup et al. (1999) and Bansal and Ochoa (2012) find that countries in warmer regions are typically poorer per capita than their counterparts in cooler climates and that their economies and equity markets grow more slowly.[3] Burke, Hsiang, and Miguel (2015) present strong evidence that the productivity of countries increases along with increases in temperature until an annual average temperature of 13 °C, with productivity declining significantly at higher temperatures, suggesting a non-linear relationship between economic productivity and temperature. In a study based on US municipal-level data, Dell et al. (2009) find a negative association between temperature and economic output.[4]

The above studies suggest that ongoing climate change will negatively affect economic activities and outputs as average temperatures rise (IPCC, 2007).[5] Burke et al. (2015) write that by 2100 unmitigated warming could reduce average global income by about 23%, Fuss (2016) that climate change destroys financial assets and disrupts related economic activities, and Covington and Thamotheram (2015) that a diversified global stock portfolio will lose 5–20% of its value if warming reaches 4 °C or more.

The amount of daylight associated with seasonality can also affect human psychology and mood with concomitant effects on economic behavior. For example, Kamstra, Kramer, and Levi (2003) find that "seasonal affective disorder" affects stock returns.[6] Hirshleifer and Shumway (2003) find that sunny weather makes traders more upbeat which leads to positive stock returns, and Cao and Wei (2005) that higher temperature is associated with apathy and lower stock returns and lower temperature with aggressiveness and higher stock returns.[7] Similarly, Novy-Marx (2014) points to the effect of New York City temperatures on stock returns.

Prior studies have also examined the effect of extreme weather events on the economy. Kreft and Eckstein (2014) state that global extreme weather events over the 1993–2012 period led to more than 530,000 casualties and over $2.5 trillion in economic losses. Jahn (2013) shows that from 1980 to 2012 the number of extreme weather events and losses from them increased significantly worldwide. Based on the 1970–2002 cross-country data, Yang (2008) shows that stronger storms are associated with higher fatalities and economic losses. Similarly, Hsiang and Narita (2012) show that extreme weather events such as windstorms lead to reduced growth rates as well as economic losses. Based on data from 28 Caribbean nations, Hsiang (2010) finds that while cyclones have a significant negative impact on some industries, they can have a significant positive impact on others, for example, on the construction industry. In a within-country study, Deryugina (2011) finds that government aid mitigates the economic losses from hurricanes and, as a result, there is no significant effect on county-level earnings ten years after their occurrence.[8]

In sum, although many studies have presented evidence of climate and climate-related factors having an economic impact within and across countries, there is a lack of direct evidence of an impact at the firm level, which would be very useful in understanding its impact on managerial decisions and firm performance. Extreme weather can negatively affect firm performance because it can inflict physical damage on firm fixed assets (e.g., property, plant, and equipment), decreasing not only the value of the assets, but also the earnings that might have been generated from them. Given the sometimes significant negative effect of extreme weather conditions on local economies, firm property, and business operations, we present the following hypothesis:

Hypothesis 1: Climate risk is negatively (positively) associated with a firm's financial returns (earnings volatility).

Effect of Climate Risk on Financial Policy

Climate change and increasingly extreme weather necessitate substantial organizational transformations (Wilbanks et al., 2007). A large body of literature addresses the notion of organizational resilience to climate change, which is the ability of an organization to systematically absorb, and recover from, the adverse effects of external environmental disturbance caused by weather extremes (Berkes, Colding, & Folke, 2003; Linnenluecke & Griffiths, 2010; Tschakert & Dietrich, 2010). Studies focus mainly on operational resilience to climate change, through relocation of activities, improvements in infrastructure and production techniques, and increased insurance coverage (Berkhout, Hertin, & Gann, 2006; Hoffmann, Sprengel, Ziegler, Kolb, & Abegg, 2009). Some point to the importance of organizational slack resources, such as backup facilities and financial slack (e.g., Linnenluecke, Griffiths, & Winn, 2008; Vogus & Sutcliffe, 2007; Woods, 2006). However, more studies are needed on financial slack (Linnenluecke & Griffiths, 2010). We expect that firms in countries characterized by extreme weather are more likely to maintain financial slack resources in order to improve organizational resilience to weather extremes.

Effect of climate risk on debt

Given our predicted effects of climate risk (i.e., reducing firm performance and increasing earnings volatility), we expect that firms located where extreme weather events are likely will increase financial slack resources. Debt structure is an important financial policy of this kind. Diamond (1991) posits that firms with high liquidation risk are likely to prefer long-term debt due to short-term illiquidity concerns. Hence, high cash flow volatility and the accompanying liquidation risk are likely to cause firms to take on less short-term debt. In addition, because short-term debt is subject to more frequent renegotiation it is more likely to be negatively affected by liquidity shocks (Custodio, Ferreira, & Laureano, 2013). Extreme weather can lead to liquidity shocks, and thus firms in areas characterized by extreme weather may prefer long-term debt to avoid financial constraints.[9]

Based on the above discussion, we present the following hypotheses:

Hypothesis 2: Climate risk is positively associated with firm long-term debt.

Hypothesis 3: Climate risk is negatively associated with firm short-term debt.

Effect of Climate Risk on Cash Holding

The precautionary motive is an important reason for holding cash (e.g., Bates et al., 2009; Huang, Wu, Yu, & Zhang, 2015; Opler, Pinkowitz, Stulz, & Williamson, 1999). Opler et al. (1999) find that firms are inclined to hold more cash when performance is poor or cash flow volatility is high, suggesting that firms hold more cash to cope with adverse shocks. As country-level climate risk is an adverse shock to firm operation, those in higher climate risk environments have incentives to hold more cash.

Prior studies show that high cash flow volatility leads firms to hold more cash (e.g., by paying lower cash dividends) as a hedge against operational risk (Itzkowitz, 2013; Larkin, 2013; Wang, 2012). For example, Wang (2012) shows that because losing a major customer can lead to a huge drop in cash inflow, firms tend to hold cash as a hedge against that. As we discuss above, climate risk can increase operational risk (e.g., performance volatility) and lead firms to hold more cash.

Based on the above discussion, we present the following hypotheses:

Hypothesis 4: Climate risk is positively associated with cash holding.

Hypothesis 5: Climate risk is negatively associated with cash dividends.

MEASUREMENT AND SAMPLE DATA

Measurement

We use the 2014 Global Climate Risk Index (CRI) compiled and published by Germanwatch to measure climate risk by country.[10] The CRI captures the extent to which countries have suffered direct loss associated with extreme weather-related events such as storms, floods, and heat waves (Kreft & Eckstein, 2014).[11] According to the authors, the CRI is indicative of the severity of the climate risk a country faces in the future due to climate change (Kreft & Eckstein, 2014: 3). The CRI has been widely cited by studies addressing climate change (e.g., Burnell, 2012; Rivera & Wamsler, 2014; Garschagen & Romero-Lankao, 2015), and recent scientific evidence shows that many severe weather events are attributable to climate change (Jahn, 2013; Kreft & Eckstein, 2014).

The CRI has been published annually since 2006, the 2014 edition being the ninth and most recent. There are two sets of CRI scores: annual and long-term. Annual scores are based on data pre-dating by 2 years the edition year. For example, the 2014 edition contains annual scores based on 2012 data. The long-term scores are based on data for a period of 20 years ending 2 years prior to the edition year, e.g., the long-term scores in the 2014 edition are based on the 1993–2012 data. We adopt annual scores from the 2008 to 2014 editions and the 2014 edition long-term scores.[12] That is, we use annual data, 2006–2012, and long-term data for the period 1993–2012.

The CRI is based on the following two absolute and two relative indicators of climate-related risk: (1) number of deaths, (2) number of deaths per 100,000 inhabitants, (3) sum of losses in US$ at purchasing power parity (PPP), and (4) losses per unit of Gross Domestic Product (GDP).[13] A country's index score equals that country's average ranking of all four indicators, absolute indicators (1) and (3) weighting one-sixth each, and relative indicators (2) and (4) weighting one-third each.[14] Lower index scores and the corresponding higher rankings thus indicate greater risk. For example, in the 2014 edition, Honduras has the lowest long-term CRI score of 10.17, derived from the rankings in the four indicators. Honduras is ranked Number 1 on the CRI with the most severe climate-related risk during 1993–2012. Since lower index scores indicate higher climate risk, we multiply the index scores by negative one so that higher scores indicate greater risk. For example, the Honduras score becomes −10.17.

Data

Table 1 shows the number of observations by country. There are a total of 353,906 observations, 27% of which come from the US (96,841 observations). We obtained financial data for these firms from Compustat and country-level institutional data from a number of sources (see the Appendix for details). Following the extant literature (e.g., Masulis & Mobbs, 2014), we exclude the financial and utility industries from our sample since these industries are highly regulated and are quite different from other industries. The country sample size varies between 54 and 55 countries depending on data availability.[15] Table 1 presents the descriptive statistics for country-level variables for 55 countries. Vietnam, the Philippines, Thailand, and Portugal have the highest (i.e., the least negative) long-term CRI scores: they suffered the most direct losses from weather-related events over the 1993–2012 time period. For example, in the case of Vietnam the annual average number of deaths is given as 419.70 (0.52 deaths per 100,000 inhabitants) and the annual average loss in purchasing power as $1637 million (0.91% of their GDP). Ecuador has the highest standard deviation of annual CRI (32.03). Norway, Switzerland, Denmark, Sweden, and the US are ranked the highest in terms of GDP, and Russia, China, Vietnam, India, and Venezuela ranked the highest in GDP growth. In terms of legal environment (*LEG_ENV*), the US, Finland, France, Singapore, and Hungary are ranked the highest.

METHODOLOGY AND DESCRIPTIVE STATISTICS

Methodology

We estimate the effect of climate risk on financial performance, on earnings and operating cash flow volatility, and on financial policy using the following specification:

$$\begin{aligned}&\text{Financial performance/performance volatility/}\\&\quad\text{financial policy} = \beta_0 + \beta_1\text{Climate Risk}\\&\quad + \beta_2 ROA/CFO + \beta_3 SIZE + \beta_4 Ln(age)\\&\quad + \beta_5 Intangible\ Assets + \beta_6 PPE + \beta_7 Total\ Debt\\&\quad + \beta_8 Sales\ Growth + \beta_9 LGDP + \beta_{10} GDP\ Growth\\&\quad + \beta_{11} LEG\_ENV + Industry + Year + \varepsilon. \qquad (1)\end{aligned}$$

The dependent variables are two measures of financial performance, two of earnings and operating cash flow volatility, and five of financial policies. Financial performance is measured by return-on-assets (*ROA*) and cash flows from operations (*CFO*); hence, *ROA/CFO* is not included in the control variables when testing the effect of climate risk on financial performance. *Earnings Volatility* is the standard deviation of quarterly pre-tax income scaled by total assets over the preceding five fiscal years and *Operating Cash Flow Volatility* is the standard deviation of quarterly cash flows from operations scaled by total assets over the preceding five fiscal years. Financial policy is measured by three measures of debt, *Short-term Debt*, *Long-term Debt*, and *Short and Long-term Debt*, by *Cash Holding* (cash and short-term investment scaled by lagged assets), and by *Cash Dividend* (cash dividend scaled by lagged assets). The variable of interest is *Climate Risk*, measured by annual and long-term CRI scores published by Germanwatch as described previously. The Appendix provides the variable definitions.

We control for firm characteristics including the natural log of assets (*SIZE*), the natural log of firm age (*Ln*(*age*)), intangible assets (*Intangible Assets*), net property, plant, and equipment (*PPE*), *Total Debt*, and *Sales Growth*.

The country-level macroeconomic factors we include in the regression model are log of real GDP per capita (*LGDP*) and annual growth of total GDP (*GDP Growth*), to follow previous study (Kingsley & Graham, 2017). Since CRI is likely to be affected by the size and financial performance of a country's economy, we also use *LGDP* and *GDP growth* to control for these factors. To control for a country's legal environment, we use *LEG_ENV*, the principal component extracted from *COMMON*, *ENFORCE*, and *CR*. *COMMON* refers to an indicator by La Porta, Lopez-de-Silanes, Shleifer, and Vishny (1998) that equals one if the legal origin is common law, and zero otherwise; *ENFORCE* is the law enforcement index (from the Economic Freedom of the World 2010 Annual Report) that ranges from 0 to 10, with higher values indicating greater law enforcement. *CR* is an index reflecting creditor rights, which is formed by adding four dummy variables: a dummy equal to one (1) when a country imposes restrictions, such as creditor consent or minimum dividends to file for reorganization; (2) when secured creditors are able to gain possession of their security once a reorganization petition has been approved (no automatic stay); (3) when secured creditors are ranked first in the distribution of proceeds that result from the disposition of the assets of a bankruptcy; and (4) when debtors do not retain the administration of their property pending the resolution of the reorganization. The index ranges from 0 to 4 and is based on La Porta et al. (1998) and Djankov, McLiesh, and Shleifer (2007).

Following prior literature (Le & Kroll, 2017; Marano, Tashman, & Kostova, 2017), we control industries and year fixed effects.

Descriptive Statistics

Table 2, Panel A shows the descriptive statistics for the sample used for testing for the effect of climate risk on firm performance, earnings volatility, and financial policy.[16] The required data to be included in these tests are available for a total of 55 countries, those listed in Table 1. The mean and median annual climate risks are −44.53 and −38.00, respectively, −65.59 for the annual score, and −48.00 for the long-term score. Our sample firms have a median *ROA* of 0.040, a *CFO* of 0.061, a short-term debt of 0.052, cash holdings of 10.4% of assets, and cash dividends of 0.6% of assets. The natural log of their assets (*Size*) is 6.28, the natural log of firm age (*Ln*(*age*)) is 2.197, and sales growth is 7.5%. The median value of the log of a country's per capita GDP (*LGDP*) is 10.36, the median value of *GDP Growth* is 6.3%, and the median score for legal environment (*LEG_ENV*) is 3.039.

Panel B of Table 2 provides annual CRI scores by continent.[17] They vary over time. For example, in the case of Asia the highest score (−25.80) is in year 2006 and the lowest (−57.30) in year 2012. The mean values for Asia, North America, Oceania, Africa, Latin America, and Europe are −44.37, −52.86, −36.85, −51.91, −57.82, and −62.42 and their standard deviations are 9.95, 9.67, 14.60, 13.20, 18.61, and 8.49, respectively.

Panel C of Table 2 provides the Pearson correlations between climate risk and our measures of financial performance, earnings and cash flow volatility, and financing policies. Both annual and long-term climate risk measures are negatively and significantly related to ROA, CFO, short-term debt, and cash dividends and positively related to earnings volatility, operating cash flow volatility, long-term debt, short- and long-term debt, and cash holdings. These univariate correlations are consistent with our hypotheses.

Table 2 Descriptive statistics and correlation for variables

Panel A: Descriptive statistics

Variables	Mean	SD	P25	Median	P75	No. of countries	No. of obs.
Climate Risk (Annual)	−44.53	25.11	−63.50	−38.00	−25.17	55	147,223
Climate Risk (Long term)	−65.59	31.21	−92.00	−48.00	−44.83	55	353,906
ROA	−0.005	0.212	−0.018	0.040	0.093	55	353,906
CFO	0.041	0.184	−0.003	0.061	0.127	55	326,087
Earnings Volatility	0.045	0.072	0.010	0.020	0.045	55	218,763
Operating Cash Flow Volatility	0.071	0.075	0.026	0.048	0.085	55	214,647
Short-term Debt	0.111	0.144	0.004	0.052	0.163	55	353,752
Long-term Debt	0.152	0.198	0.001	0.076	0.227	55	353,828
Short and LONG-term Debt	0.272	0.273	0.049	0.214	0.399	55	353,452
Cash Holdings	0.482	1.420	0.034	0.104	0.277	55	351,895
Cash Dividends	0.018	0.031	0.000	0.006	0.021	55	261,581
SIZE	6.532	2.935	4.372	6.280	8.486	55	353,906
Total Debt	0.625	0.411	0.365	0.569	0.774	55	353,906
Ln(age)	2.150	0.729	1.609	2.197	2.639	55	353,906
Intangible Assets	0.100	0.184	0.000	0.011	0.105	55	353,906
PPE	0.346	0.286	0.122	0.281	0.492	55	353,906
Sales Growth	0.188	0.574	−0.041	0.075	0.248	55	353,906
LGDP	9.725	1.339	9.121	10.360	10.590	55	353,906
GDP Growth	0.069	0.094	0.033	0.063	0.115	55	353,906
LEG_ENV	2.834	1.323	2.111	3.039	4.279	55	353,906

Panel B: Climate risk index by continent and year (2006–2012)

Year	Asia	North America	Oceania	Africa	Latin America	Europe
2006	−25.80	−40.55	−39.28	−63.98	−67.12	−51.72
2007	−52.81	−66.29	−41.25	−46.32	−74.45	−65.63
2008	−40.93	−53.24	−32.90	−22.97	−36.21	−60.70
2009	−44.15	−54.29	−17.04	−55.13	−55.77	−52.29
2010	−51.79	−61.07	−34.51	−56.64	−52.89	−65.76
2011	−37.83	−37.52	−25.65	−64.94	−31.16	−62.20
2012	−57.30	−57.05	−67.30	−53.37	−87.13	−78.63
Mean	−44.37	−52.86	−36.85	−51.91	−57.82	−62.42
SD	9.95	9.67	14.60	13.20	18.63	8.49

Panel C: Pearson correlation

		A	B	C	D	E	F	G	H	I	J	K
Climate Risk (Annual)	A	1										
Climate Risk (Long term)	B	0.699	1									
ROA	C	−0.034	−0.047	1								
CFO	D	−0.024	−0.044	0.647	1							
Earnings Volatility	E	0.046	0.025	−0.470	−0.414	1						
Operating Cash Flow Volatility	F	0.053	0.019	−0.302	−0.326	0.480	1					
Short-term Debt	G	−0.007	−0.029	−0.079	−0.103	0.062	0.067	1				
Long-term Debt	H	0.072	0.079	−0.012	0.016	−0.031	−0.105	0.043	1			
Short and Long-term Debt	I	0.054	0.043	−0.072	−0.048	0.033	−0.031	0.617	0.779	1		
Cash Holdings	J	0.041	0.030	−0.295	−0.360	0.262	0.181	−0.126	−0.096	−0.134	1	
Cash Dividends	K	−0.106	−0.069	0.293	0.294	−0.123	−0.005	0.017	−0.070	−0.018	−0.062	1

Note: All correlations are significant at the $p < 0.05$ level.

MAIN RESULTS

Effect of Climate Risk on Financial Performance

Table 3 presents the test results relating to the effect of climate risk on financial performance. The sample includes the 55 countries listed in Table 1. Columns (1) and (2) show the results using the annual climate risk score with return-on-asset (*ROA*) and cash flow from operation (*CFO*) as the dependent variables. In both columns, we find the coefficients of the annual climate risk score to be significantly negative, indicating that higher climate risk is significantly associated with worse firm performance.[18] For example, in Column (1), the non-transformed coefficient (i.e., all coefficients in Tables 3, 4, and 5 have been multiplied by 100 for exposition purposes) of the annual climate risk is −0.00047 ($p < 0.000$), with the 95% confidence interval of between −0.00053 and −0.00040.[19] This

Table 3 Climate risk and firm performance

	(1) ROA	(2) CFO	(3) ROA	(4) CFO
Climate Risk (Annual)	−0.047	−0.030		
	(0.003)	(0.003)		
Climate Risk (Long term)			−0.009	−0.008
			(0.002)	(0.002)
SIZE	0.021	0.014	0.020	0.015
	(0.000)	(0.000)	(0.000)	(0.000)
Ln(age)	0.009	0.012	0.013	0.018
	(0.001)	(0.001)	(0.001)	(0.001)
Intangible Assets	0.119	0.122	0.110	0.097
	(0.005)	(0.005)	(0.004)	(0.004)
PPE	0.092	0.120	0.099	0.121
	(0.003)	(0.003)	(0.003)	(0.003)
Total Debt	−0.094	−0.063	−0.089	−0.059
	(0.003)	(0.003)	(0.002)	(0.002)
Sales Growth	0.028	−0.007	0.016	−0.021
	(0.002)	(0.002)	(0.001)	(0.001)
LGDP	−0.021	−0.014	−0.013	−0.004
	(0.001)	(0.001)	(0.001)	(0.001)
GDP Growth	0.055	−0.019	0.068	0.016
	(0.008)	(0.007)	(0.005)	(0.005)
LEG_ENV	0.002	0.008	−0.006	−0.004
	(0.001)	(0.001)	(0.001)	(0.001)
Intercept	0.055	0.009	0.029	−0.033
	(0.011)	(0.010)	(0.008)	(0.007)
Industry/year	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes
No. of observations	147,223	145,749	353,906	326,087
Adjusted R^2	0.209	0.165	0.182	0.158
F	120.3	98.49	162.6	135.2
No. of countries	55	55	55	55

This table presents the regression results of the impact of climate risk on financial performance. Regressions include year and industry fixed effects. The standard errors reported in parentheses are heteroskedasticity robust and clustered at the firm level. To conserve space, we do not report the coefficient estimates for the industry and year dummies. For exposition purposes, we multiply the coefficients on climate risk by 100. All variables are defined in the Appendix.

indicates that moving from the first quartile (−63.50) to the third quartile (−25.17) of the annual climate risk score can reduce a firm's *ROA* by 1.8 percentage points.[20] The effect size of the annual climate risk is 0.0027, with the 95% confidence interval of between 0.0022 and 0.0032.[21]

Similarly, in Column (2), the coefficient on the annual climate risk is −0.00030 ($p < 0.000$), with the 95% confidence interval of between −0.00036 and −0.00025. Moving from the first quartile (−63.50) to the third quartile (−25.17) of the annual climate risk score reduces a firm's *CFO* by 1.15 percentage points.[22] The effect size of the annual climate risk is 0.0015, with the 95% confidence interval of between 0.0011 and 0.0019. Columns (3) and (4) show similar results when using long-term climate risk as both coefficients are significantly negative. In sum, consistent with Hypothesis 1, Table 3 shows that higher climate risk can have significantly negative economic consequences on firm performance.

Effect of Climate Risk on Earnings Volatility

Table 4 shows the results of estimating the relationship between climate risk and earnings volatility. As we do not have the data necessary to calculate earnings volatility for Ecuadorian firms, the sample consists of 54 countries.[23] Columns (1) and (2) show the results for the annual climate risk and Columns (3) and (4) for the long-term climate risk. Results in Columns (1) and (2) indicate that the coefficients for the annual climate risk are significantly positive for accounting earnings volatility (coefficient = 0.0005 and $p < 0.000$) and

Table 4 Climate risk and earnings volatility

	(1) *Earnings Volatility*	(2) *Operating Cash Flow Volatility*	(3) *Earnings Volatility*	(4) *Operating Cash Flow Volatility*
Climate Risk (Annual)	0.005	0.016		
	(0.001)	(0.001)		
Climate Risk (Long term)			0.001	0.004
			(0.001)	(0.001)
ROA	−0.098		−0.103	
	(0.002)		(0.001)	
CFO		−0.079		−0.075
		(0.003)		(0.002)
SIZE	−0.005	−0.007	−0.006	−0.008
	(0.000)	(0.000)	(0.000)	(0.000)
Ln(age)	−0.004	−0.005	−0.005	−0.002
	(0.001)	(0.001)	(0.000)	(0.000)
Intangible Assets	−0.013	−0.030	−0.010	−0.030
	(0.002)	(0.002)	(0.001)	(0.002)
PPE	−0.017	−0.027	−0.015	−0.026
	(0.001)	(0.002)	(0.001)	(0.001)
Total Debt	0.028	0.024	0.027	0.025
	(0.001)	(0.001)	(0.001)	(0.001)
Sales Growth	0.012	0.010	0.014	0.009
	(0.001)	(0.001)	(0.000)	(0.000)
LGDP	−0.002	−0.004	−0.001	−0.003
	(0.000)	(0.000)	(0.000)	(0.000)
GDP Growth	0.014	0.031	0.028	0.047
	(0.003)	(0.003)	(0.003)	(0.003)
LEG_ENV	0.004	−0.002	0.005	−0.002
	(0.000)	(0.000)	(0.000)	(0.000)
Intercept	0.081	0.166	0.058	0.144
	(0.005)	(0.006)	(0.003)	(0.005)
Industry/year	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes
No. of observations	117,014	115,170	218,763	212,439
Adjusted R^2	0.278	0.197	0.310	0.203
F	110.3	88.79	203.3	113.6
No. of countries	54	54	54	54

This table presents the regression results of the impact of climate risk on performance volatility. Regressions include year and industry fixed effects. The standard errors reported in parentheses are heteroskedasticity robust and clustered at the firm level. To conserve space, we do not report the coefficient estimates for the industry and year dummies. For exposition purposes, we multiply the coefficients on climate risk by 100. All variables are defined in the Appendix.

operating cash flow volatility (coefficient = 0.00016 and $p < 0.000$). The 95% confidence interval of the coefficient is between 0.00026 (0.00013) and 0.00069 (0.00018), when the dependent variable is earnings volatility (operating cash flow volatility). The effect size of annual climate risk is 0.0003 (0.0026), with the 95% confidence interval of between 0.0001(0.0020) and 0.0005 (0.0032), when the dependent variable is earnings volatility (operating cash flow volatility).

Results in Columns (3) and (4) show that long-term climate risk has an insignificantly positive coefficient for earnings volatility but a significantly positive coefficient for operating cash flow volatility.[24] In sum, consistent with Hypothesis 1, Table 4 indicates that higher climate risk is associated with greater earnings volatility and operating cash flow volatility, consistent with extreme weather events disrupting normal operations.

Effect of Climate Risk on Financing Policies

Table 5 presents the results of our tests of the relationship between climate risk and a firm's policies on short-term and long-term debt, cash holding, and cash dividends. Panel A uses annual climate risk and Panel B long-term climate risk. In

Table 5 Climate risk and financial policy

Panel A: Climate risk (Annual) and financial policy

	(1) *Short-term Debt*	(2) *Long-term Debt*	(3) *Short and Long-term Debt*	(4) *Cash Holdings*	(5) *Cash Dividends*
Climate Risk (Annual)	−0.059	0.075	0.013	0.364	−0.020
	(0.003)	(0.003)	(0.004)	(0.026)	(0.001)
ROA	−0.127	−0.107	−0.273	−1.703	0.060
	(0.003)	(0.005)	(0.007)	(0.050)	(0.001)
SIZE	0.003	0.008	0.011	−0.037	−0.001
	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)
Ln(age)	−0.012	0.004	−0.007	−0.175	−0.002
	(0.001)	(0.001)	(0.002)	(0.010)	(0.000)
Intangible Assets	0.050	0.266	0.364	−0.385	0.010
	(0.004)	(0.006)	(0.007)	(0.036)	(0.001)
PPE	0.087	0.243	0.371	−0.159	0.006
	(0.003)	(0.005)	(0.006)	(0.034)	(0.001)
Leverage				−0.469	0.005
				(0.020)	(0.001)
Sales Growth	0.013	0.013	0.029	0.122	−0.002
	(0.001)	(0.001)	(0.002)	(0.014)	(0.000)
LGDP	−0.029	0.013	−0.019	0.150	−0.003
	(0.001)	(0.001)	(0.002)	(0.009)	(0.000)
GDP Growth	0.040	−0.085	−0.048	1.180	0.033
	(0.006)	(0.006)	(0.009)	(0.061)	(0.002)
LEG_ENV	0.009	−0.012	−0.001	−0.059	0.001
	(0.001)	(0.001)	(0.001)	(0.007)	(0.000)
Intercept	0.322	−0.110	0.216	0.248	0.046
	(0.012)	(0.014)	(0.020)	(0.094)	(0.003)
Industry/year	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes
No. of observations	147,183	147,202	147,029	146,156	107,824
Adjusted R^2/Pseudo R^2	0.156	0.239	0.263	0.298	0.177
F/χ^2	132.7	150.2	219.9	77.01	97.92
No. of countries	55	55	55	55	55

Panel B: Climate risk (Long term) and financial policy

	(1) *Short-term Debt*	(2) *Long-term Debt*	(3) *Short and Long-term Debt*	(4) *Cash Holdings*	(5) *Cash Dividends*
Climate Risk (Long term)	−0.040	0.063	0.016	0.115	−0.010
	(0.002)	(0.002)	(0.003)	(0.016)	(0.001)
ROA	−0.128	−0.084	−0.250	−1.491	0.039
	(0.002)	(0.003)	(0.005)	(0.031)	(0.001)
SIZE	0.005	0.006	0.012	−0.025	−0.001
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Ln(age)	−0.008	0.010	0.002	−0.166	−0.001
	(0.001)	(0.001)	(0.001)	(0.006)	(0.000)
Intangible Assets	0.059	0.275	0.389	−0.296	0.009
	(0.003)	(0.005)	(0.006)	(0.025)	(0.001)
PPE	0.084	0.246	0.379	−0.076	0.008
	(0.003)	(0.004)	(0.004)	(0.022)	(0.001)
Leverage				−0.405	0.003
				(0.013)	(0.000)
Sales Growth	0.010	0.012	0.022	0.181	−0.002
	(0.001)	(0.001)	(0.001)	(0.009)	(0.000)
LGDP	−0.027	0.012	−0.017	0.093	−0.003
	(0.001)	(0.001)	(0.001)	(0.005)	(0.000)

Table 5 (*Continued*)

Panel B: Climate risk (Long term) and financial policy					
	(1) *Short-term Debt*	(2) *Long-term Debt*	(3) *Short and Long-term Debt*	(4) *Cash Holdings*	(5) *Cash Dividends*
GDP Growth	0.003	−0.016	−0.016	0.595	0.023
	(0.004)	(0.004)	(0.006)	(0.033)	(0.001)
LEG_ENV	0.007	−0.005	0.005	−0.008	0.000
	(0.001)	(0.001)	(0.001)	(0.005)	(0.000)
Intercept	0.270	−0.080	0.184	0.318	0.036
	(0.009)	(0.011)	(0.016)	(0.082)	(0.002)
Industry/year	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes
No. of observations	353,752	353,828	353,452	351,895	261581
Adjusted R^2/Pseudo R^2	0.141	0.232	0.261	0.234	0.156
F/χ^2	157.0	201.5	314.3	94.86	126.2
No. of countries	55	55	55	55	55

This table presents the regression results of the impact of climate risk on financial volatility. Regressions include the year and industry fixed effects. The standard errors reported in parentheses are heteroskedasticity robust and clustered at the firm level. To conserve space, we do not report the coefficient estimates for the industry and year dummies. For exposition purposes, we multiply the coefficients on climate risk by 100. All variables are defined in the Appendix.

Panel A, Column (1) indicates that annual climate risk is negatively associated with *Short-term Debt* (coefficient = −0.00059, $p < 0.000$), with the 95% confidence interval of between −0.00064 and −0.00054. The effect size of annual climate risk is 0.0083, with the 95% confidence interval of between 0.0074 and 0.0092.

Columns (2) and (3), on the other hand, show that annual climate risk is positively associated with both *Long-term Debt* and *Short- and Long-term Debt*.[25] In Panel B, Columns (1), (2), and (3) show similar results for long-term climate risk. In sum, consistent with Hypotheses 2 and 3, we find climate risk to be associated with higher long-term but lower short-term debt.

In Panel A of Table 5, Columns (4) and (5) show that annual climate risk is positively associated with cash holding and negatively associated with cash dividends. The results have economic significance. For example, in Column (4), the coefficient of 0.00364 on the annual climate risk indicates that moving from the first quartile (−63.5) to the third quartile (−25.17) of the annual climate risk score can increase a firm's cash holding by 13.95% of its total assets.[26] Similarly, in Column (5), the coefficient of −0.0002 for annual climate risk indicates that moving from the first quartile (−63.5) to the third quartile (−25.17) of the annual climate risk score can decrease a firm's cash dividend by 0.77% of its total assets.[27] The results in Columns (4) and (5) in Panel B also show that long-term climate risk is also positively associated with cash holding and negatively with cash dividends.[28] These results are consistent with Hypotheses 4 and 5.[29]

Overall, the evidence relayed in Table 5 suggests that firms in countries with higher climate risk borrow less short-term and more long-term, hold more cash, and issue lower cash dividends. This is consistent with using extra cash holding to mitigate cash flow volatility that may result from extreme weather events.

Effects of Vulnerable Industries

Different industries have different levels of vulnerability to extreme weather conditions. Climate risk can adversely affect firm profitability in at least two ways. First, extreme weather can inflict physical damage on assets and deprive a firm of potential revenue (Reisch, 2005). According to the Sustainability Accounting Standards Board (2016), Wilbanks et al. (2007), and McCarthy, Canziani, Leary, Dokken, and White (2001), industries with heavy non-deployed and long-lived capital assets are especially vulnerable to these kinds of loss. Industries of this kind include communications, energy (e.g., mining and oil extraction), healthcare, and utilities. Second, extreme weather can disrupt normal operations and lead to operating losses. The SASB (2016) and Wilbanks et al. (2007) show that industries dependent on moderate weather, with both an extended supply chain and a reliance on infrastructure, are likely to see their operations disrupted by extreme climate. Examples of these kinds of industries are agriculture and food

Table 6 Climate risk and vulnerable industries

	(1) ROA	(2) CFO	(3) Earnings Volatility	(4) Operating Cash Flow Volatility	(5) Short-term Debt	(6) Long-term Debt	(7) Short and Long-term Debt	(8) Cash Holdings	(9) Cash Dividends
Climate Risk (Annual)	−0.066	−0.047	0.004	0.012	−0.072	0.053	−0.018	0.294	−0.018
	(0.004)	(0.003)	(0.000)	(0.001)	(0.002)	(0.004)	(0.003)	(0.026)	(0.001)
Vulnerable Industries	−0.007	0.022	0.006	0.003	−0.034	−0.005	−0.039	0.281	0.001
	(0.004)	(0.004)	(0.000)	(0.001)	(0.002)	(0.004)	(0.003)	(0.152)	(0.001)
Climate Risk (Annual) × *Vulnerable Industries*	−0.021	−0.002	0.002	0.002	−0.017	0.030	0.014	0.351	−0.004
	(0.008)	(0.007)	(0.001)	(0.002)	(0.005)	(0.008)	(0.007)	(0.059)	(0.002)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry/year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of observations	147,223	145,749	117,014	115,170	147,008	147,202	147,029	146,156	107,824
Adjusted R^2/Pseudo R^2	0.172	0.128	0.322	0.160	0.120	0.212	0.232	0.299	0.159
F/χ^2	312.7	234.8	2925	348.3	797.9	360.7	1542	75.82	271.6

This table presents the regression results of the impact of climate risk on vulnerable industries. *Vulnerable Industries* is an indicator variable that equals one for Agriculture (Fama–French Industry Code 1), Business Services (Code 34), Communication (Code 32), Energy [Mines (Code 28), Coal (Code 29), and Oil (Code 30)], Food Products (Code 2), Health Care (Code 11), and Transportation (Code 40), and zero otherwise. Regressions include the year fixed effects. The standard errors reported in parentheses are heteroskedasticity robust and clustered at the firm level. To conserve space, we do not report the coefficient estimates for the industry and year dummies. For exposition purposes, we multiply the coefficients on climate risk by 100. All variables are defined in the Appendix.

manufacturing that depend on land, water, and sun, and industries that provide business services and transportation. There is also support for this view from Fleming, Kirby, and Ostdiek (2006), Hsiang (2010), and Challinor, Watson, Lobell, Howden, Smith, and Chhetri (2014). Based on that literature, we consider agriculture, energy (including mining and oil extraction), food products, healthcare, communications, business services, and transportation to be vulnerable industries.[30] *Vulnerable industries* are coded one.

We include the interaction term *Climate Risk (Annual)* × *Vulnerable Industries* in Eq. (1) and present the regression results in Table 6. Columns (1), (3), (5), (6), (7), (8), and (9) show that the coefficients are generally significant and take the expected sign. Overall, this indicates that the adverse effect of climate risk on reducing ROA, increasing earnings volatility, borrowing less short-term but more long-term, and reducing cash dividends is more pronounced for these vulnerable industries. This industry-specific result provides additional supporting evidence for the link between climate risk and financial performance and financing policies.

ROBUSTNESS TESTS

Instrument Variable Method: Population Density

Because some of the country-level and firm-level variables are difficult to quantify and control, we used an instrumental variable method to re-estimate our models. In that robustness test, we chose population density as the instrumental variable because it is likely to be highly correlated with climate risk (Albouy, Graf, Kellogg, & Wolff 2013), but unlikely to be correlated with our dependent variables. We define *Population Density* as the number of people per square kilometer. We obtained country-year-level data from the World Bank. In the first stage, we regressed *Climate Risk (Long term)* on *Population Density* and on the firm-level control variables included in Eq. (1): *SIZE*, *Ln(age)*, *Intangible Assets*, *PPE*, and *Sales Growth*. We then computed the fitted value of *Climate Risk (Long term)* and included it in our second-stage regression based on Eq. (1). Panel A of Table 7 reports the first-stage results. As predicted, the coefficient of *Population Density* is negative and significant ($p < 0.000$), indicating a significantly negative association between population density and climate risk. Panel B of Table 6 shows that including fitted

Table 7 Climate risk on firm performance and financing choices: Instrument variable method

Panel A: First stage to estimate fitted value of climate risk

	(1) *Climate Risk (Long term)*
Population Density	−0.167
	(0.000)
SIZE	−0.020
	(0.000)
Ln(age)	0.026
	(0.002)
Intangible Assets	0.010
	(0.006)
PPE	0.021
	(0.005)
Sales Growth	0.019
	(0.001)
Intercept	−0.542
	(0.016)
Industry/year	Yes
No. of observations	353,906
Pseudo R^2	0.394

Panel B: Climate risk and firm performance

	(1) *Earnings Volatility*	(2) *Operating Cash Flow Volatility*	(3) *Earnings Volatility*	(4) *Operating Cash Flow Volatility*
Fitted Climate Risk (Long term)	−0.056	−0.032	0.006	0.004
	(0.003)	(0.003)	(0.001)	(0.001)
Controls	Yes	Yes	Yes	Yes
No. of observations	353,906	326,087	218,763	212,439
Adjusted R^2	0.184	0.159	0.310	0.203

Panel C: Climate risk and financial policy

	(1) *Short-term Debt*	(2) *Long-term Debt*	(3) *Short and Long-term Debt*	(4) *Cash Holdings*	(5) *Cash Dividends*
Fitted Climate Risk (Long term)	−0.043	0.036	−0.011	0.026	−0.009
	(0.003)	(0.003)	(0.005)	(0.022)	(0.001)
Controls	Yes	Yes	Yes	Yes	Yes
No. of observations	353,752	353,828	353,452	351,895	261,581
Adjusted R^2/Pseudo R^2	0.149	0.245	0.263	0.236	0.152

This table presents the OLS estimation results relating climate risk to firm performance and financial policy using instrument variable method. Panel A presents the first-stage OLS model estimation results. Specifically, the dependent variable in the first stage is *Climate Risk (Long term)*. *Population Density* is the number of people (in 1000) per squared kilometer of land area, and Panels B and C report OLS results of examining the relation between the fitted value of *Climate Risk (Long term)* on firm performance and financing choices, respectively. The standard errors reported in parentheses are heteroskedasticity robust and clustered at the firm level. To conserve space, we do not report the coefficient estimates for the industry and year dummies. For exposition purposes, we multiply the coefficients on climate risk by 100. All variables are defined in the Appendix.

Climate Risk (Long term) in the second-stage regression does not change our results, and hence that they are unlikely to be driven by omitted country-level variables.

Propensity-Score-Matched Sample

In a second robustness test, we used a propensity-score-matched sample to address the concern, the results of which may be driven by differences in firm characteristics between high-climate risk and low-climate risk groups (Ghoul, Guedhami, & Kim, 2017).[31] We define *High Climate Risk* as firm-year climate risk above the sample median. In the first stage, we regressed our *High Climate Risk* dummy on the firm-level control variables included in Eq. (1): *SIZE*, *Ln(age)*, *Intangible Asset*, *PPE*, and *Sales Growth*. Panel A of Table 8 reports the regression results. We then computed the propensity score for each

Table 8 Climate risk on firm performance and financing choices: propensity score matching

Panel A: First-stage propensity score matching

	(1) *High Climate Risk*
SIZE	0.068
	(0.003)
Ln(age)	0.579
	(0.010)
Intangible Assets	−0.118
	(0.034)
PPE	−0.414
	(0.027)
Sales Growth	0.219
	(0.014)
Intercept	1.734
	(0.119)
Industry/year	Yes
No. of observations	167,234
Pseudo R^2	0.143

Panel B: Climate risk and firm performance

	(1) *Earnings Volatility*	(2) *Operating Cash Flow Volatility*	(3) *Earnings Volatility*	(4) *Operating Cash Flow Volatility*
High Climate Risk	−0.014	−0.012	0.001	0.003
	(0.003)	(0.002)	(0.001)	(0.001)
Controls	Yes	Yes	Yes	Yes
No. of observations	74,372	74,372	74,372	74,372
Adjusted R^2	0.227	0.185	0.290	0.158

Panel C: Climate risk and financial policy

	(1) *Short-term Debt*	(2) *Long-term Debt*	(3) *Short and Long-term Debt*	(4) *Cash Holdings*	(5) *Cash Dividends*
High Climate Risk	−0.009	0.050	0.040	0.035	−0.008
	(0.002)	(0.003)	(0.004)	(0.017)	(0.001)
Controls	Yes	Yes	Yes	Yes	Yes
No. of observations	74,372	74,372	74,372	74,372	74,372
Adjusted R^2/Pseudo R^2	0.165	0.287	0.281	0.170	0.172

This table presents the OLS estimation results relating climate risk to firm performance and financial policy using propensity score matching method. Panel A presents the first-stage Probit model estimation results. Specifically, the dependent variable in the first stage is *High Climate Risk*, an indicator variable that equals one if *Climate Risk (Long term)* is above sample median, and zero otherwise. We regress *High Climate Risk* on firm characteristics and use the estimated coefficients from this first-stage model to compute the propensity score for each observation in our sample. We then match each firm-year that in the high-climate risk group with a firm-year in the low-climate risk group, with the closest propensity score. Panel B reports OLS results of examining the relation between climate risk on firm performance and financing choices, using propensity-score-matched sample. The standard errors reported in parentheses are heteroskedasticity robust and clustered at the firm level. To conserve space, we do not report the coefficient estimates for the industry and year dummies. For exposition purposes, we multiply the coefficients on climate risk by 100. All variables are defined in the Appendix.

observation in our sample. We matched each firm-year in the high-climate risk group with the firm-year in the low-climate risk group with the closest propensity score. Panel B of Table 8 reports the OLS estimation result of the relationship between climate risk, financial performance, and financing choices using the matched sample under Eq. (1). The results are unchanged.

Insurance Coverage

We used country-level growth in non-life insurance payments as a proxy for country-level insurance coverage (*Insurance*). The data come from Global Insurance Market Trends. In unreported results, we find that the level of insurance coverage is higher for countries with higher climate risk. We then tested whether insurance coverage can mitigate adverse effects of climate risk on firm performance and earnings volatility by interacting country-level insurance coverage with CRI. We find significantly positive coefficients for *ROA* and *CFO* and negative ones for *Earnings Volatility* and *Operating Cash Flow Volatility*. This suggests that insurance coverage can mitigate the adverse effect of climate risk on firm performance and earnings volatility.[32]

CRI for US Multinational Firms

Given the ability of multinational firms to move their operations out of high-climate risk areas, we adjusted the CRI based on the countries where a given multinational is active. Lack of national sales data and segment data for multinationals not headquartered in the US limited somewhat our ability to test firm sensitivity to climate risk. As an alternative approach, we obtained from the Compustat segments database US multinational firm revenue for specific geographic areas. We merged those data with country-year-level CRI and computed the arithmetic average CRI for each firm weighted by its revenue from different countries. We attempted to replicate the previous regressions using this weighted *CRI*. Consistent with our previous results, we find in unreported results a negative impact from climate risk on operating performance measured as CFO and the same impact on financing decisions that we reported earlier.

Alternative Measure of Global Climate Risk

To provide a robustness test for our measure of climate risk, we used another measure of global climate risk. We obtained the Global Climate Report from the National Oceanic and Atmospheric Administration (NOAA) website.[33] The Global Climate Report has included since 2009 a Significant Climate Anomalies and Events section. Based on these data, we created a dummy variable (SCAE), which equals one if a country suffers one or more climatic anomalies or events, and zero otherwise. The variable is not based on the loss of GDP and thus is free of the influence of a country's economic development and performance. We replicated the previous tests using SCAE (instead of CRI). As shown in Table 9, the results continue to be robust, suggesting that they are not driven by GDP level or growth.

Other Robustness Tests

We conducted an array of additional robustness tests. The results, which are not reported, are similar. First, we excluded all US observations,

Table 9 Alternative measure of extreme climate risk – extreme climate events

	(1) *ROA*	(2) *CFO*	(3) *Earnings Volatility*	(4) *Operating Cash Flow Volatility*	(5) *Short-term Debt*	(6) *Long-term Debt*	(7) *Short and Long-term Debt*	(8) *Cash Holdings*	(9) *Cash Dividends*
SCAE	−0.007	−0.001	0.004	0.007	−0.030	0.036	0.004	0.168	−0.003
	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.016)	(0.001)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry/year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of observations	85,275	84,447	69,313	68,160	85,238	85,264	85,132	84,656	60,881
Adjusted R^2/Pseudo R^2	0.176	0.122	0.269	0.201	0.159	0.231	0.251	0.297	0.173
F/χ^2	330.6	230.2	75.34	73.73	106.4	121.2	156.3	59.49	63.84

This table presents the regression results of using an alternative measure of extreme climate risk – extreme climate event. SCAE refers to an indicator variable that equals one if a country suffers one or more significant climate anomalies or events, and zero otherwise. Source: Significant Climate Anomalies and Events, Global Climate Report from National Oceanic and Atmospheric Administration (NOAA). Regressions include the year fixed effects. The standard errors reported in parentheses are heteroskedasticity robust and clustered at the firm level. To conserve space, we do not report the coefficient estimates for the industry and year dummies. For exposition purposes, we multiply the coefficients on climate risk by 100. All variables are defined in the Appendix.

which constitute 27% of our sample (see Table 1), in order to check that the findings are not US driven. Second, following Edwards (1992), we used country-weighted least squares regression to control for the different weights of countries in the sample. Third, we ran the four indicators of climate risk one at a time (instead of combined). Fourth, we restructured the CRI giving equal weights to its four indicators. Fifth, while Goodwin and Wu (2014) suggest that controlling for country-level fixed effects will reduce the likelihood of observing significant results, we find that including them does not alter our conclusion that climate risk has a profound impact on important financing decisions. Sixth, we measured the climate risk index for the year prior to financial policies. Seventh, we defined the financial crisis period separately for each country based on GDP growth rate and find that the results are robust to either interacting financial crisis years with climate risk or dropping financial crisis years from the sample.[34]

CONCLUSION

Our work contributes to a growing literature on the impact of climate risk on firm decisions. It is one of the first cross-country studies of the direct impact of global climate risk on public firm policies and performance. We provide evidence that managers of public firms across the globe weigh the loss due to extreme weather-related events such as storms, floods, and heat waves, i.e., *climate risk*, when making financing choices. First, as expected, we find that climate risk is negatively associated with firm earnings and positively associated with earnings volatility. This implies that firms cannot fully offset climate risk by insuring against it, either because they are unwilling or unable to do so. We also show that the managers of firms in countries characterized by severe climate risk tend to hold more cash, rely less on short-term and more on long-term borrowing, and pay lower cash dividends. We find similar results using an instrumental variable approach, propensity score matching, path analysis, and an alternative measure of climate risk. Our results are consistent with firms creating financial slack in order to maintain 'organizational resilience' against the threat of climate risk. They are more pronounced in the case of industries that are more vulnerable to climate risk. Our conclusions are invariant to the timing of financial crises that can affect different countries at different times. The strategies documented in our article appear to be consistent with attempts by managers to mitigate the increased volatility and uncertainty of future earnings and cash flows caused by higher climate risk.

ACKNOWLEDGEMENTS

We thank the valuable comments from the Editor-in-Chief Alain Verbeke, Editor Gary Biddle, the three anonymous reviewers, and the participants of workshop at the University of Kentucky and the Mid-year Conference of International Accounting Section of American Accounting Association. Chong Wang acknowledges the financial support from Hong Kong Polytechnic University Start-up Fund and the National Natural Science Foundation of China (Fund # 71332008).

NOTES

[1]According to United Nations International Strategy for Disaster Reduction (UNISDR, 2009), risk is the "combination of the probability [of occurrence] of a certain event and its negative consequences."

[2]A large part of the economic damage emanating from extreme weather events is not insured, especially in the case of developing countries (Andersen, 2001; Bals, Warner, & Butzengeiger, 2006). Catastrophic insurance usually covers only damage to the means of production (e.g., property), not indirect losses such as lost proceeds from property that is destroyed, not losses that other agents may suffer, e.g., loss of supplies from damaged property (Bals et al. 2006). Hence underlying our study is the assumption that firms cannot fully insure against climatic risk. To the extent that they can do so, we anticipate that our findings will be less significant.

[3]Bansal and Ochoa (2012) propose that equity returns in countries with higher temperatures (i.e., those closer to the Equator) have a positive temperature risk premium; they also show that increases in global temperature negatively affect the economic growth of countries closer to the Equator.

[4]Albouy et al. (2013) posit that US households prefer a certain temperature level and find a cost of living premium in areas with such levels.

[5]Concern about the effect of rising temperatures is growing. Pal and Eltahir (2016) predict that the temperature in Southwest Asia will rise beyond the habitable level if global warming is left unabated.

[6]Seasonal affective disorder refers to an extensively documented medical condition whereby the shortness of the daylight in fall and winter leads to greater depression and, in turn, heightened risk aversion.

[7]Prior literature tends to treat sunshine and temperature as two distinct weather variables. For example, Howarth and Hoffman (1984) show that skepticism is positively associated with temperature and negatively associated with the amount of sunshine.

[8]Interest in climate change has resulted in a recent strand of studies in this area including some that focus on the impact on firm valuation, as carbon dioxide emissions, hazardous chemicals, and other pollutants may result in onerous regulatory requirements, financial or reputational damage, or costly litigation. Konar and Cohen (2001) show that intangible asset valuation is negatively associated with levels of emitted toxic chemicals, Matsumura et al. (2014) that carbon emissions can negatively affect firm value, and Beatty and Shimshack (2010) that firms suffer from negative market returns when poorly rated on managing (i.e., measuring, reporting, and reducing) greenhouse gas emissions. Based on US evidence, Chava (2014) finds that investors charge firms with higher greenhouse emissions and hazardous chemical discharges more for equity and debt capital. Using a European sample, Tu (2014) finds that firms with better carbon management performance have better share performance. On the other hand, Anderson, Bolton, and Samama (2016) document that carbon risk is currently underpriced by financial markets and investors can hedge against climate risks without losing any returns. Finally, Clapp, Alfsen, Torvanger, and Lund (2015) argue that climate science should play a crucial role in verifying that the "green projects" of firms are climate friendly. However, these studies do not directly study the impact of climate events (as opposed to concerns) on firm valuation and decision-making.

[9]Atta-Mensah (2016) suggests that countries and firms can issue weather-linked bonds to hedge against volatility due to weather-dependent assets.

[10]Firms in larger countries can possibly move from a country's high-climate risk area to one where the risk is less. That possibility would tend to reduce the robustness of any findings. At the same time, many firms cannot relocate (e.g., some retailers and firms in communication and transportation).

[11]"Geological factors like earthquakes, volcanic eruptions and tsunamis, for which data is also available, are not included as they are not weather-related per se and therefore not climate change-related" (Kreft & Eckstein, 2014: 16).

[12]We were not able to obtain annual scores from the 2006 and 2007 editions.

[13]Economic losses comprise "all elementary loss events which have caused substantial damage to property or persons" or in other words, direct losses (Kreft & Eckstein, 2014: 16). Indirect losses, i.e., the losses that firms experience due to damaged assets and those of their customers, are not included. However, they are highly correlated to direct losses (Hallegatte, 2008; Kowalewski & Ujeyl, 2012).

[14]Because indicators 3 and 4, sum of losses in US$ at PPP and losses as a percent of GDP, are likely to be affected by the economic size and performance of a country, we control for level and change of GDP in our multivariate regression analysis. Also, according to Kreft and Eckstein (2014: 20), "the indicator 'absolute losses in US$' is identified by purchasing power parity (PPP), because using this figure better expresses how people are actually affected by the loss of one US$ than by using nominal exchange rates."

[15]One limitation of this study is that we do not account for how a firm might be affected by climate risk associated with its material operations located overseas.

[16]We winsorized all the continuous variables at the 1 and 99% levels.

[17]To save space, we do not provide the annual CRI by countries where the results are similar.

[18]Results not reported here indicate that both annual and long-term climate risk scores are positively associated with firms having negative extraordinary items and discontinued items.

[19]Meyer, Witteloostuijn, and Beugelsdijk (2017) point out that it is important to discuss the confidence interval of the coefficient. To save space, we do not provide the confidence intervals in the tables.

[20]It is calculated as follows: $(-25.17 - (-63.50)) \times (-0.00047) = -0.0108$.

[21]Effect size refers to the magnitude of the effects (Ferguson, 2009).

[22]It is calculated as follows: $(-25.17 - (-63.50)) \times (-0.0003) = -0.0115$.

[23]The quarterly pre-tax income (PI) of firms in Ecuador is not given. Thus, we are not able to calculate *Earnings Volatility* for Ecuador and so cannot include Ecuador in our sample, leading to the reduction of sample size from 55 countries in Table 3 to 54 countries in Table 4.

[24]Rountree et al. (2008) argue that investors are mainly concerned about the cash flow (as opposed to accounting) component of earnings volatility. Moreover, illiquidity issues are usually caused by cash flow volatility, not earnings volatility.

[25]The results indicate that these firms have higher long-term debt and total debt, which is a sign of financial distress (Banerjee, Dasgupta, & Kim, 2008) and can be a result of poor earnings performance resulting from extreme weather events.
[26]It is calculated as follows: $(-25.17 - (-63.5)) \times (0.00364) = 0.1395$.
[27]It is calculated as follows: $(-25.17 - (-63.5)) \times (-0.0002) = -0.0077$.
[28]Our results are robust to controlling for whether a country's company law or commercial code requires firms to distribute certain percentage of their income as dividends (La Porta et al., 1998).
[29]The results in Table 5 may be due to extreme weather or to volatility in higher earnings and cash holdings as suggested in Table 4. We use path analysis (e.g., Wright, 1934) to examine these potential dependencies where annual extreme weather is treated as the direct path and earnings volatility as the mediated (indirect) path. We find that both direct and mediated paths are significant and positive, indicating that the financing policies are affected by both organizational resilience and earnings volatility.
[30]We use the Fama–French Industry classification.
[31]Using propensity-score-matched sample is an effective method to address endogeneity issue in cross-country studies (e.g., Ghoul et al., 2017).
[32]Results are available from the authors.
[33]https://www.ncdc.noaa.gov/sotc/global.
[34]For convenience, we use a definition of a recession commonly used in the business press involving a fall in GDP for two successive quarters. [Note that the NBER defines a recession more broadly as "a significant decline in economic activity spread across the economy, lasting more than a few months, normally visible in real GDP, real income, employment, industrial production, and wholesale-retail sales" (NBER, 2008)].

REFERENCES

Albouy, D., Graf, W., Kellogg, R., & Wolff, H. 2013. Climate amenities, climate change, and American quality of life. Working Paper. Cambridge, MA: National Bureau of Economic Research.

Andersen, T. 2001. *Managing economic exposures of natural disasters: Exploring alternative financial risk management opportunities and instruments* (p. 2001). Washington, DC: Natural Disasters Dialogue First Meeting.

Anderson, M., Bolton, P., & Samama, F. 2016. Hedging climate risk. *Financial Analysts Journal,* 72(3): 13–32.

Atta-Mensah, J. 2016. Poverty, climate risk and weather-indexed bonds. *Journal of Mathematical Finance,* 6(2): 275–292.

Bals, C., Warner, K., & Butzengeiger, S. 2006. Insuring the uninsurable: Design options for a climate change funding mechanism. *Climate Policy,* 6(6): 637–647.

Banerjee, S., Dasgupta, S., & Kim, Y. 2008. Buyer–supplier relationships and the stakeholder theory of capital structure. *Journal of Finance,* 63(5): 2507–2552.

Bansal, R., & Ochoa, M. 2012. Temperature, aggregate risk, and expected returns. Unpublished Working Paper No. 17575. Cambridge, MA: National Bureau of Economic Research.

Bates, T., Kahle, K., & Stulz, R. 2009. Why do US firms hold so much more cash than they used to? *Journal of Finance,* 64(5): 1985–2021.

Beatty, T., & Shimshack, J. 2010. The impact of climate change information: New evidence from stock market. *Journal of Economic Analysis and Policy,* 10(1): 1–29.

Berkes, F., Colding, J., & Folke, C. (eds.). 2003. *Navigating social–ecological systems: Building resilience for complexity and change*. Cambridge: Cambridge University Press.

Berkhout, F., Hertin, J., & Gann, D. M. 2006. Learning to adapt: Organizational adaptation to climate change impacts. *Climatic Change,* 78(1): 135–156.

Burke, M., Hsiang, S. M., & Miguel, E. 2015. Global non-linear effect of temperature on economic production. *Nature,* 527(7577): 235–239.

Burnell, P. 2012. Democracy, democratization and climate change: Complex relationship. *Democratization,* 19(5): 813–842.

Cao, M., & Wei, J. 2005. Stock market returns: A note on temperature anomaly. *Journal of Banking & Finance,* 29(6): 1559–1573.

Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. 2014. A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change,* 4(4): 287–291.

Chava, S. 2014. Environmental externalities and cost of capital. *Management Science,* 60(9): 2223–2247.

Clapp, C. S., Alfsen, K. H., Torvanger, A., & Lund, H. F. 2015. Influence of climate science on financial decisions. *Nature Climate Change,* 5(2): 84–85.

Covington, H., & Thamotheram. R. 2015. The case for forceful stewardship (part 1): The financial risk from global warming. Working Paper. Cambridge, MA: Cambridge University and University of Oxford.

Custodio, C., Ferreira, M., & Laureano, L. 2013. Why are US firms using more short-term debt? *Journal of Financial Economics,* 108(1): 182–212.

Dell, M., Jones, B., & Olken, B. A. 2009. Temperature and income: Reconciling new cross-sectional and panel estimates. *American Economic Review,* 99(2): 198–204.

Dell, M., Jones, B., & Olken, B. A. 2014. What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature,* 52(3): 740–798.

Deryugina, T. 2011. The role of transfer payments in mitigating shocks: Evidence from the impact of hurricanes. Working Paper. Champaign, IL: University of Illinois.

Diamond, D. 1991. Debt maturity structure and liquidity risk. *Quarterly Journal of Economics,* 106(3): 709–737.

Dichev, I., & Tang, V. 2009. Earnings volatility and earnings predictability. *Journal of Accounting and Economics,* 47(1): 160–181.

Djankov, S., McLiesh, C., & Shleifer, A. 2007. Private credit in 129 countries. *Journal of Financial Economics,* 84(2): 299–329.

Edwards, S. 1992. Trade orientation, distortions, and growth in developing countries. *Journal of Development Economics,* 39(1): 31–58.

Ferguson, C. J. 2009. An effect size primer: A guide for clinicians and researchers. *Professional Psychology,* 40(5): 532–538.
Fleming, J., Kirby, C., & Ostdiek, B. 2006. Information, trading, and volatility: Evidence from weather-sensitive markets. *The Journal of Finance,* 61(6): 2899–2930.
Francis, J., LaFond, R., Olsson, P. M., & Schipper, K. 2004. Costs of equity and earnings attributes. *The Accounting Review,* 79(4): 967–1010.
Fuss, S. 2016. Climate economics: Substantial risk for financial assets. *Nature Climate Change,* 6(7): 659–660.
Gallup, J., Sachs, J., & Mellinger, A. 1999. Geography and economic development. *International Regional Science Review,* 22(2): 179–232.
Garschagen, M., & Romero-Lankao, P. 2015. Exploring the relationships between urbanization trends and climate change vulnerability. *Climate Change,* 133(1): 37–52.
Ghoul, S. E., Guedhami, O., & Kim, Y. 2017. Country-level institutions, firm value, and the role of corporate social responsibility initiatives. *Journal of International Business Studies,* 48(3): 360–385.
Goodwin, J., & Wu, D. 2014. Is the effect of industry expertise on audit pricing an office-level or a partner-level phenomenon? *Review of Accounting Studies,* 19(4): 1532–1578.
Hallegatte, S. 2008. An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina. *Risk Analysis,* 28(3): 779–799.
Hirshleifer, D., & Shumway, T. 2003. Good day sunshine: Stock returns and the weather. *Journal of Finance,* 58(3): 1009–1032.
Hoffmann, V. H., Sprengel, D. C., Ziegler, A., Kolb, M., & Abegg, B. 2009. Determinants of corporate adaptation to climate change in winter tourism: An econometric analysis. *Global Environmental Change,* 19(2): 256–264.
Howarth, E., & Hoffman, M. S. 1984. A multidimensional approach to the relationship between mood and weather. *British Journal of Psychology,* 75(1): 15–23.
Hsiang, S. M. 2010. Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. *Proceedings of the National academy of Sciences of the United States of America,* 107(35): 15367–15372.
Hsiang, S. M., & Narita, D. 2012. Adaptation to cyclone risk: Evidence from the global cross-section. *Climate Change Economics,* 3(2): 1250011-1–1250011-28.
Huang, T., Wu, F., Yu, J., & Zhang, B. 2015. Political risk and dividend policy: Evidence from international political crises. *Journal of International Business Studies,* 46(5): 574–595.
IPCC. 2007. Climate change 2007: Synthesis Report, Fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC).
Itzkowitz, J. 2013. Customers and cash: How relationships affect suppliers' cash holdings. *Journal of Corporate Finance, 19,* 159–180.
Jahn, M. 2013. Economics of extreme weather events in cities: Terminology and regional impact models. HWWI research Paper 143, Hamburg Institute of International Economics.
Kamstra, M. J., Kramer, L. A., & Levi, M. D. 2003. Winterblues: A SAD stock market cycle. *American Economic Review,* 93(1): 324–343.
Kingsley, A. F., & Graham, B. A. 2017. The effects of information voids on capital flows in emerging markets. *Journal of International Business Studies,* 48(3): 324–343.
Konar, S., & Cohen, M. A. 2001. Does the market value environmental performance? *The Review of Economics and Statistics,* 83(2): 281–289.
Kowalewski, J., & Ujeyl, G. 2012. Estimating direct and indirect damages from storm surges: The case of Wilhelmsburg/Hamburg. In F. Klijn & T. Schweckendiek (Eds.), *Comprehensive flood risk management: Research for policy and practice*. Delft: CRC Press.
Kreft, S., & Eckstein, D. 2014. *Global climate risk index 2014*. Bonn: Germanwatch.
La Porta, R., Lopez-de-Silanes, F., Shleifer, A., & Vishny, R. W. 1998. Law and finance. *Journal of Political Economy,* 106(6): 1113–1155.
Larkin, K. 2013. Brand perception, cash flow stability, and financial policy. *Journal of Financial Economics,* 110(1): 232–253.
Le, S., & Kroll, M. 2017. CEO international experience: Effects on strategic change and firm performance. *Journal of International Business Studies,* 48(5): 573–595.
Linnenluecke, M. K., & Griffiths, A. 2010. Beyond adaption: Resilience for business in light of climate change and weather extremes. *Business & Society,* 49(3): 477–511.
Linnenluecke, M. K., Griffiths, A., & Winn, M. I. 2008. Organizational adaptation and resilience to extreme weather events. Paper presented at the Annual Meetings of the Academy of Management, Anaheim, CA (Recipient of the Carolyn Dexter Best International Paper Award)
Lipe, R. 1990. The relation between stock returns and accounting earnings given alternative information. *The Accounting Review,* 65(1): 49–71.
Marano, V., Tashman, P., & Kostova, T. 2017. Escaping the iron cage: Liabilities of origin and CSR reporting of emerging market multinational enterprises. *Journal of International Business Studies,* 48(3): 386–408.
Masulis, R., & Mobbs, S. 2014. Independent director incentives: Where do talented directors spend their limited time and energy? *Journal of Financial Economics,* 111(2): 406–429.
Matsumura, E., Prakash, R., & Vera-Munoz, S. 2014. Firm-value effects of carbon emissions and carbon disclosures. *The Accounting Review,* 89(2): 695–724.
McCarthy, J., Canziani, O., Leary, N., Dokken, D., & White, K. 2001. *Climate change 2001: Impacts, adaptation, and vulnerability: Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.
Meyer, K., Witteloostuijn, A., & Beugelsdijk, S. 2017. What's in a p? Reassessing best practices for conducting and reporting hypothesis-testing research. *Journal of International Business Studies,* 48(5): 535–551.
Minton, B., & Schrand, C. 1999. The impact of cash flow volatility on discretionary investment and the costs of debt and equity financing. *Journal of Financial Economics,* 54(3): 423–460.
National Bureau of Economic Research (NBER). 2008. The NBER's recession dating procedure. *National Bureau of Economic Research.* http://www.nber.org/cycles/jan08bcdc_memo.html.
Nordhaus, W. D. 2006. Geography and macroeconomics: New data and new findings. *Proceedings of the National academy of Sciences of the United States of America,* 103(10): 3510–3517.
Novy-Marx, R. 2014. Predicting anomaly performance with politics, the weather, global warming, sunspots, and the stars. *Journal of Financial Economics,* 112(2): 137–146.
Opler, T., Pinkowitz, L., Stulz, R., & Williamson, R. 1999. The determinants and implications of corporate cash holdings. *Journal of Financial Economics,* 52(1): 3–46.
Pal, J. S., & Eltahir, E. A. B. 2016. Future temperature in southwest Asia projected to exceed a threshold for human adaptability. *Nature Climate Change,* 6(2): 197–200.
Reisch, M. 2005. Katrina's impact: In hurricane's aftermath, chemical firms face higher costs and lower earnings. *Chemical & Engineering News,* 83(38): 8.
Rivera, C., & Wamsler, C. 2014. Integrating climate change adaptation, disaster risk reduction and urban planning: A review of Nicaraguan policies and regulations. *International Journal of Disaster Risk Reduction,* 7: 78–90.
Ronen, J., & Sadan, S. 1981. *Smoothing income numbers: objectives, means, and implications*. Boston, MA: Addison-Wesley Publishing.
Rountree, B., Weston, J., & Allayannis, G. 2008. Do investors value smooth performance? *Journal of Financial Economics,* 90(3): 237–251.

SASB (Sustainability Accounting Standards Board). 2016. Climate risk technical bulletin. https://www.eenews.net/assets/2016/10/20/document_cw_01.pdf.
Stulz, R. 1990. Managerial discretion and optimal financing policies. *Journal of Financial Economics,* 26(1): 3–27.
Tschakert, P., & Dietrich, K. 2010. Anticipatory learning for climate change adaptation and resilience. *Ecology and Society,* 15(2): 11.
Tu, D. 2014. Do the stock markets price climate change risks? Working Paper. Paris: HEC. http://www.vernimmen.net/ftp/DoStockMktsPriceClimateChangeRisks_Danni_TU.pdf.
United Nations International Strategy for Disaster Reduction (UNISDR). 2009. UNISDR Terminology on Disaster Risk Reduction, Geneva. http://www.unisdr.org/_les/7817UNISDRTerminologyEnglish.pdf.
Vogus, T., & Sutcliffe, K. 2007. Organizational resilience: Towards a theory and research agenda, *2007 IEEE International Conference on Systems, Man and Cybernetics*, Montreal, Quebec, pp. 3418–3422.
Wang, J. 2012. Do firms' relationships with principal customers/suppliers affect shareholders' income? *Journal of Corporate Finance,* 18: 860–878.
Wilbanks, T. J., Romero Lankao, P., Bao, M., Berkhout, F., Cairncross, S., Ceron, J.-P., et al., 2007. Industry, settlement and society. *Climate Change*, 357–390.
Woods, D. 2006. Essential characteristics of resilience. In E. Hollnagel, D. D. Woods, & N. Leveson (Eds.), *Resilience engineering: Concepts and precepts* (pp. 21–34). Burlington, VT: Ashgate.
Wright, S. 1934. The method of path coefficients. *Annals of Mathematical Statistics,* 5: 161–215.
Yang, D. 2008. Coping with disaster: The impact of hurricanes on international financial flows, 1970–2002. *The BE Journal of Economic Analysis & Policy,* 8(1): 1–43.

APPENDIX

See Table 10.

Table 10 Variable definitions

Variable	Definition
Climate risk index	
Climate Risk (Annual)	Annual Climate Risk Index from Germanwatch's 2008–2014 editions (for the years 2006–2012) scaled by (−1). Higher score indicates higher Climate risk in the year. Sources: Germanwatch
Climate Risk (Long term)	Accumulated Climate Risk Index from Germanwatch's 2014 edition (covering the years 1993–2012) scaled by (−1). Higher score indicates higher Climate risk from 1993 to 2012. Sources: Germanwatch
High Climate Risk	Indicator variable that equals one if a firm-year's *Climate Risk (Long term)* is higher than the sample median, and zero otherwise. Sources: Germanwatch
SCAE	Indicator variable that equals one if a country suffers one or more climate anomalies or events (SCAE), and 0 otherwise. Source: Significant Climate Anomalies and Events
Financial performance	
ROA	Pre-tax Income (PI) scaled by lagged assets (AT). Sources: Compustat
CFO	Cash flows from operations (OANCF) scaled by total assets. Sources: Compustat
Performance volatility	
Operating Cash Flow Volatility	Cash flow volatility, measured by the standard deviation of quarterly cash flows from operations (OANCF) scaled by total assets (AT) over the preceding five fiscal years. Sources: Compustat
Earnings Volatility	Earnings volatility, measured by the standard deviation of quarterly pre-tax income (PI) scaled by total assets (AT) over the preceding five fiscal years. Sources: Compustat
Financial policy	
Short-term Debt	Short-term debt (DLC), scaled by lagged assets (AT). Sources: Compustat
Long-term Debt	Long-term debt (DLTT), scaled by lagged assets (AT). Sources: Compustat
Short and Long-term Debt	The sum of short- and long-term debt, scaled by lagged assets (AT). Sources: Compustat
Total Debt	Total liability (LT), scaled by lagged assets (AT). Sources: Compustat
Cash Holdings	Cash and short-term investment (CHE), scaled by lagged assets (AT). Sources: Compustat
Cash Dividends	Cash dividends (DVPD), scaled by lagged assets (AT). Sources: Compustat
Country-level control variables	
COMMON	Indicator that equals one if the legal origin is common law, and zero otherwise. Sources: La Porta et al. (1998)
EarnVol	Country-level control variable for earnings volatility. Sources: Compustat

Table 10 (*Continued*)

Variable	Definition
Factor	Principal component of the country's legal tradition (common law versus code law), strength of investor rights, and ownership concentration as developed by La Porta et al. (1998); Legal tradition refers to the indictor variable (COMMON), which equals one if the legal origin is common law, and zero otherwise (La Porta et al., 1998). Investor Rights is measured by an index aggregating the shareholder rights labeled as "anti-director rights." The index is formed by adding 1 when (1) the country allows shareholders to mail their proxy vote to the firm, (2) shareholders are not required to deposit their shares prior to the general shareholders' meeting, (3) cumulative voting or proportional representation of minorities in the board of directors is allowed, (4) an oppressed minorities mechanism is in place, (5) the minimum percentage of share capital that entitles a shareholder to call for an extraordinary shareholders' meeting is less than or equal to 10% (the sample median), or (6) shareholders have preemptive rights that can be waived only by a shareholders' vote. The index ranges from zero to six (La Porta et al., 1998; Djankov et al., 2007). Ownership concentration refers to the average percentage of common shares owned by the three largest shareholders in the 10 largest non-financial, privately owned domestic firms in a given country (La Porta et al., 1998). Sources: La Porta et al. (1998) and Djankov et al. (2007)
GDP Growth	Annual growth of total GDP. Sources: International Financial Statistics (IFM)
LEG_ENV	Principal component extracted from COMMON, ENFORCE, and CR. COMMON refers to an indicator that equals one if the legal origin is common law, and zero otherwise. ENFORCE refers to the law enforcement index that ranges from 0 to 10, with higher values indicating greater law enforcement. CR refers to creditor rights, which is formed by adding (1) when the country imposes restrictions, such as creditors consent or minimum dividends to file for reorganization; (2) when secured creditors are able to gain possession of their security once the reorganization petition has been approved (no automatic stay); (3) when secured creditors are ranked first in the distribution of the proceeds that result from the disposition of the assets of a bankrupt firm; and (4) when the debtor does not retain the administration of its property pending the resolution of the reorganization. The index ranges from 0 to 4. Sources: La Porta et al. (1998), Djankov et al. (2007), Economic Freedom of the World
LGDP	Log of GDP per capita, in constant 2000 US dollars. Sources: World Bank
Population Density	People (in 1000) per sq. km of land area. Sources: World Bank
Firm-level control variables	
SIZE ($ million)	The natural logarithm of asset (AT) at the beginning of the year. Sources: Compustat
Total Debt	Total liability, scaled by lagged assets (AT). Sources: Compustat
Intangible Assets	Intangible assets (INTAN), scaled by lagged assets (AT). Sources: Compustat
PPE	Net property, plant, and equipment (PPENT) divided by lagged assets. Sources: Compustat
ROA	Pre-tax Income (PI) scaled by lagged assets (AT). Sources: Compustat
R&D	Research and development expenditures (XRD) scaled by lagged assets (AT). Sources: Compustat
Sales Growth	Sales (SALE) change computed scaled by sales in the last fiscal year. Sources: Compustat
Ln(age)	Natural logarithm of firm age, which is calculated starting from the first year the firm appeared in the Compustat database. Sources: Compustat
Interaction variables	
Vulnerable Industries	Indicator variable that equals one for Agriculture (Fama–French Industry Code 1), Business Services (Code 34), Communication (Code 32), Energy [Mines (code 28), Coal (Code 29), and Oil (Code 30)], Food Products (Code 2), Health Care (Code 11), and Transportation (Code 40), and zero otherwise. Sources: Compustat

ABOUT THE AUTHORS

Henry He Huang is an Associate Professor of Accounting at Yeshiva University's Sy Syms School of Business. His research focuses on the impact of external monitoring mechanisms on firms' accounting practice, valuation, and internal governance. His recent research interests include the value relevance of religiosity and climate risk across the countries.

Joseph Kerstein is an Associate Professor of Accounting at the Sy Syms School of Business, Yeshiva University. He graduated in 2000 with a Ph.D. from the Wharton School of Business. His primary research interests include identifying potential agency problems such as earnings management, resource usage by doctors under fee-for-service contracts, and managerial responses to climate risk.

Chong Wang is an Assistant Professor at the School of Accounting & Finance, Hong Kong Polytechnic University. He possesses a Ph.D. in Accounting from Xiamen University (2013) and another Ph.D. in Accounting from University of Kentucky (2017). His research interests include accounting quality, banking, bank loan contracting, and climate change risk.

Accepted by Gary Biddle, Area Editor, 14 October 2017. This article has been with the authors for three revisions.

Annex 546

Y. Jin & S. Zhang, "Credit Rationing in Small and Micro Enterprises: A Theoretical Analysis", *Sustainability*, 2019

sustainability

MDPI

Article

Credit Rationing in Small and Micro Enterprises: A Theoretical Analysis

Yuhuan Jin * and Sheng Zhang *

School of Public Policy and Administration, Xi'an Jiaotong University, Xi'an 710049, China
* Correspondence: yuhuanjin628@stu.xjtu.edu.cn (Y.J.); zhangsheng@stu.xjtu.edu.cn (S.Z.); Tel.: +86-029-8266-5254 (S.Z.)

Received: 31 January 2019; Accepted: 1 March 2019; Published: 4 March 2019

check for updates

Abstract: One of the features of credit markets is that borrowers are sometimes rationed in the amount that they can borrow, which differentiates them from other markets. Small and micro enterprises (SMEs) are more likely to be eliminated than large and medium-sized enterprises under credit rationing. However, SMEs play a significant role in employment creation and growth of gross domestic products in developing countries. So, it is of great significance to study the reasons why SMEs are more vulnerable to credit constraints. By considering the differences in characteristics between SMEs and large and medium-sized enterprises, we established a theoretical model with endogenous enterprise size, and by considering banks' screening principles before and after the loan approval, we have analyzed the micro-mechanism in which there are significant differences in credit availability between SMEs and large and medium-sized enterprises. Our conclusion indicates that credit rationing in SMEs is the result of the rational choice by banks for the purpose of profit maximization.

Keywords: financing constraint; asymmetric information; small and micro enterprises; credit rationing; big data

1. Introduction

SMEs refer to natural person enterprises and legal person enterprises with small production scale, small number of employees and assets, including small enterprises, micro-enterprises, family-workshop enterprises as well as individual industrial and commercial households. In the economic society, SMEs play an irreplaceable role in increasing employment, improving people's livelihood and promoting economic growth [1,2]. Financing is the basic work of enterprise management. The establishment, survival, and development of any enterprise need financing. However, financing obstacles inhibited the efficiency of operation and the growth of enterprises. The major source of financing obstacles for enterprises is credit rationing, which refers to a situation that among observationally identical loan applicants, some get a loan whereas others are denied credit, and those who do not have access to loans will not be able to borrow even if they are willing to pay higher interest rates; in another case, no matter how adequate the supply of loans, there are always some borrowers can't get access to loans at any level of interest rate [3].

Enterprise size is considered to be one of the priority indicators to judge the financing obstacles of enterprises [4]. Zott and Amit (2007) contend that Large enterprises have more resources to undertake new products or projects which, if successful, can be implemented on a larger scale and made profitable through better access to large markets [5,6]. But, Uhlaner et al. (2012) argue that SMEs are more flexible, and managers are closer to operational levels, being able to make decisions more dynamically [7–10]. Gou Q et al. (2014) found that the smaller the enterprise size, the higher the probability of being rationed [11]. By cross-country evidence, Demirguckunt et al. (2010) show that small enterprises are more constrained in their operation and growth than large enterprises and access to financial services features importantly among the constraints [12]. Beck et al. (2006) also indicate that small enterprises consistently report higher financing obstacles than large and medium-sized enterprises [13]. Small enterprises do not only report higher financing obstacles but also more adversely affected by these obstacles. Beck, Demirgüç-Kunt, and Maksimovic (2004) find that small enterprises' financing obstacles have almost twice the effect on their growth that large enterprises' financing obstacles do [14].

In response to this situation, governments and financial institutions of many countries have taken a lot of measures to deal with the financing constraints in SMEs. However, the effect of these measures is quite limited, for more than a decade, credit availability of SMEs also reflected that the financing problems of SMEs in developing countries have not been well solved [15–17].

Research on the mechanism of credit rationing in SMEs is still in its infancy. Baltensperger (1978) and Stiglits & Weiss (1981) explored the financing difficulties of borrowers from the perspective of credit rationing, considered that credit rationing comes from adverse selection and moral hazard caused by asymmetric information, so even though borrowers are willing to pay the non-price and price terms in the contract, their loan demand will still not be met [3,18]. Yang (2012) also believes that the main reasons why it is difficult for SMEs to obtain loans are information asymmetry, high cost, and credit rationing [19]. Demirgüç-Kunt and Maksimovic (1998) find that financing constraints are lower in countries with more efficient legal systems [20]. Laeven (2003) and Gelos and Werner (2002) find that financial liberalization relaxes financing constraints of enterprises, in particular for smaller enterprises [21,22].

For the consideration of the enterprise size, Coase (1937) indicate that enterprise boundaries could affect the allocation of Resources [23]. This has received much attention in theoretical and empirical studies in economics and finance [24–27]. Traditionally, in China, the classification of the enterprise by size was based on production capacity rather than on sales or the number of employees, as in western countries [28–30]. Dang et al. (2018) employed natural logarithm forms of total assets, total sales, and market value of equity to measure the enterprise size [31]. Smyth et al. (1975) also use employment, invested capital, and net assets (capital employed) as alternative measures of enterprise size [32].

However, research on financing constraints of SMEs in foreign academic circles began in the 1990s. After many years of study, rich results have been accumulated, but the financing market system and policy support system, as well as the institutional environment in developed countries, have been relatively perfect, therefore, scholars pay more attention to the financing constraints of SMEs under perfect market conditions, the theoretical explanation put forward by them are not completely suitable for the actual situation in developing countries. SMEs in developing countries are facing more serious financing constraints. The theoretical and empirical research on financing constraints of SMEs has not been carried out in depth yet. In addition, although some scholars have used the credit rationing theory to explain the financing constraints of borrowing enterprises, they have not considered the variable of enterprise size, so they can not accurately explain the problem of "financing is difficult and expensive" for SMEs.

Therefore, on the basis of summarizing existing literatures, by considering the main disadvantages of SMEs which distinguished them from large and medium-sized enterprises, that is, by characterizing the differences between SMEs and large and medium-sized enterprises in terms of their project success probability and capital appreciation ability, we have introduced the variable of enterprise size into the traditional credit rationing model. We contend that, with other things being equal, the average success probability of SMEs' projects is lower than that of large and medium-sized enterprise, and in the case of success, the average return of SMEs' projects is less than that of large and medium-sized enterprise. In light of these problems caused by the enterprise size factor, we systematically analyzed banks' screening principles before and after the loan approval. According to the analysis, we explained the internal mechanism of credit rationing in SMEs under imperfect market conditions.

The research finds that, before making a loan, banks will comprehensively assess the risk of the borrowing enterprises, SMEs' initial asset size is usually below the critical collateral value, which made them unable to transmit their risk levels, and SMEs' loan size is usually below the minimum loan size, which would cause higher costs to banks. Besides, compared with large and medium-sized enterprises, SMEs lack tangible assets as collateral, have a lower proportion of public property rights, and exists a greater degree of information asymmetry with banks. After the loan has been made, SME at lower living standards have a stronger incentive to increase current consumption at the expense of future investment returns, and the increased credit diversion will decrease borrowing enterprise's project expected returns. All these factors resulting in lower expected bank profits. Considering this, banks will apply strict credit rationing to prevent credit risk, thus leading to the financing constraints in SMEs.

We highlight several empirical implications. First, our measurement of the enterprise size provides some insights to business finance researchers and bank credit decision makers who need quantify the factor of enterprise size in their work. Second, it pushes forward researchers' understanding of the reasons why the barriers of the accessibility to credit for SMEs are greater. Finally, our work could help banks and government and other institutions to apply appropriate methods to ease enterprise financing constraint problems. However, the limitation of this article is that we just did a theoretical analysis, what should be further done is an empirical test with data.

This paper is organized as follows: the second part presented the relevant hypotheses and established the model, and the third part analyzed the main disadvantages of SMEs as compared with large and medium-sized enterprises. Section IV described the screening mechanism before the loan issuance. Section V analyzed the risk prevention mechanism after the loan issuance and the resulting credit rationing. The last section summarized this article and puts forward the policy recommendations for alleviating the financing constraints in SMEs.

2. The Model

2.1. Assumptions about Enterprises

Suppose in a competitive credit market, there are a number of banks and enterprises. These enterprises are of different sizes, which can be divided into two groups — SMEs and large and medium-sized enterprises, represented by $i = 1, 2$ respectively. The initial asset size of SMEs are W_1, and the initial asset size of large and medium-sized enterprises are W_2, where $W_1 < W_2$, that is, the asset size of SMEs is smaller than that of large and medium-sized enterprises. Each enterprise needs to finance a project that requires a fixed amount of investment L, where $W_i < L$, as a result, each enterprise could provide collateral with a positive value, however, the initial assets are not sufficient to cover the cost of the investment project. The average success probability of group i's project is p_i, and get a positive return $G_i(K)$ once successful, where $G'_i(K) > 0, G''_i(K) < 0$ and K is the aggregated value of inputs, which is less than or equal to the loan amount L, the probability of failure is $1 - p_i$, and get *0* in case of failure, where $p_i \in (0, 1)$. Assume that as long as the project is successful and G_i is high enough, the enterprise will repay the loan, that is, there is no possibility of intentional default. Enterprise's preferences are described by the Von Neumann-Morgenstern utility function of their ultimate wealth, denoted by U, where $U' > 0$, assume that the borrowing enterprises are all risk-neutral, that is $U'' = 0$, and satisfying the assumption that its utility is negative infinity when their property of individual rationality is zero, which means $U(0) = -\infty$.

2.2. Assumptions about Banks

Suppose that each bank has enough capital, that is, there is no shortage of funds in the credit market, and the deposit interest rate (opportunity cost) of the bank is μ. Banks compete in the credit market by offering credit contracts (L, r, C), where the terms L, r, C represent loan size, interest rate, and collateral requirement respectively, they are all non-negative and $r > \mu$. The contract should satisfy the feasibility constraints at the same time, that is, the principal and interest to be repaid are greater than the level of collateral, namely, $L(1 + r) \geq C$. It is assumed that banks can costlessly divide borrowing enterprises into SMEs group and large and medium-sized enterprises group. Banks know the average success probability of each group, but for each specific size group, banks are not aware of the success probability for each particular enterprise, moreover, the cost of supervising the behavior of the enterprise after the loan issuance for the bank is enormous. Assume that the loan review costs to banks are $c = f(\eta, \sigma)$, where η indicates the proportion of public property rights of the borrowing enterprise and σ indicates the degree of information asymmetry between the borrowing enterprise and the bank, it is obvious that $f'(\eta) < 0, f'(\sigma) > 0$, which means that the larger the proportion of public property rights of the borrowing enterprise, the smaller the loan review costs of the bank, and that the greater the degree of information asymmetry between the borrowing enterprise and the bank, the greater the loan review costs of the bank.

The use of collateral generally involves various costs, which include costs of necessary legal documentation, regulatory or insurance costs of the asset to maintain the value of the collateral at the agreed level, as well as implicit costs of the borrower being forced to relinquish discretionary use of the asset. Denote these costs by $Q(C)$ with $Q(0) = 0$ and $Q'(C) > 0$. Assume that $Q(C) = \xi C$ and these costs will be paid by the borrower (In general, Q(C) will be shared by the borrower and lender, say, the borrower pay αQ and the lender (1–αQ). However, if lender and borrower can negotiate on α, Yuk-Shee Chan et al. (1985) indicated that the optimal solution will be $\alpha = 1$ [33]. Therefore, we suppose the bank will choose to assume all these costs here to simplify the exposition.). Suppose that the liquidation value of each unit of the collateral is δ times the original value, that is, the assets realization ratio of the collateral is δ, in which $0 < \delta < 1$.

Based on the above assumptions, expected bank profits ($E\pi$) and expected enterprise utility (ρ) are as follows:

$$E\pi = p_i L(1 + r) + (1 - p_i)\delta_i C - f(\eta, \sigma) - L(1 + \mu) \tag{1}$$

$$\rho = p_i U[G_i(K) - L(1 + r) + W_i] + (1 - p_i)U[W_i - (1 + \xi)C] - U(W_i) \tag{2}$$

3. Disadvantages of SMEs

Although SMEs have their own advantages and importance, they also have distinctive defects which made their financing more restricted relative to large and medium-sized enterprises. In this section, we will analyze the main disadvantages of SMEs which distinguished them from large and medium-sized enterprises.

A common problem in SMEs is that the proportion of fixed assets to total assets is too low. The core competitiveness of SMEs is often manifested in intangible assets such as intellectual property rights and brand value, thus lack of valid and collateralizable fixed assets. Fixed assets such as business premises and equipment are mainly obtained by renting or leasing. Even if these SMEs own the equipment themselves, the liquidity of their equipment are generally poor and are of low assessment value, thus unable to meet the standard of bank's collateral requirements, it is, therefore, difficult to meet the contractual terms of banks [34–36]. As a result, banks are unable to effectively control the credit risk. But in practice, banks mainly use mortgages or secured loans to lend to SMEs, for lack of valid assets as collateral, even SMEs have strong growth potential, it is difficult for them to obtain credit or other financial support through formal channels, such as banks, consequently turn into the main victim in credit rationing.

On the other hand, most SMEs are in highly competitive industries, they are vulnerable to the market environment and national policies, as well as economic cycle fluctuations [37–39]. SMEs are generally newly established enterprises with few employees and limited initial development funds, as a result, their production scale is small, their market competitiveness is weak, and their ability to resist risks is poor [40,41]. SMEs also lack detailed credit histories, therefore, banks are unable to accurately identify their credit's status and operational risks. Moreover, SMEs loans generally have "small loan scale", "short loan period" as well as "urgent and frequent loan demand", banks are faced with higher transaction costs when lending to SMEs with smaller capital needs [42]. Based on the above analysis, the rest of this section mathematically characterized the differences between

SMEs and large and medium-sized enterprises in terms of their project success probability and capital appreciation ability.

Suppose banks are able to correctly recognize that there are two differences in the average characteristics of SMEs and large and medium-sized enterprises. Firstly, other things being equal, the average risk of SMEs is greater than that of large and medium-sized enterprises, in other words, the average success probability of SMEs' projects is lower than that of large and medium-sized enterprises:

$$p_1 < p_2 \tag{3}$$

Secondly, under the same external environment and production inputs, once successful, the average return of SMEs' projects is less than that of large and medium-sized enterprises:

$$G_1(K) \leq G_2(K)\ \ \forall \mathrm{K} \tag{4}$$

For enterprises of different sizes, the difference between the average success probability of their projects implied by (3) reflects the low diversification of SME resources. Microenvironmental events can easily affect the overall operation of SMEs, whereas large and medium-sized enterprises are better able to eliminate the volatility in their production processes. For the difference between the average return of their projects in the case of success, firstly, it may reflect some scale economy in the production process, perhaps large and medium-sized enterprises can obtain better quality and more timely inputs. Secondly, it may reflect the greater experience and skill of large and medium-sized enterprises in using modern techniques.

Based on the above assumptions that the average success probability of SMEs' projects is lower than that of large and medium-sized enterprises and that the average return of SMEs' projects in the event of success is less than that of large and medium-sized enterprises, by considering the impact of these differences on expected bank profits, it is easy to demonstrate that, for given contract terms $(\overline{L}, \overline{C}, \overline{r})$, expected bank profits are higher on loans to large and medium-sized enterprises than on loans to SMEs (Here, our implicit assumption is that banks have the same review costs for loans to all enterprises. In fact, these costs would be relatively higher per yuan loaned to SMEs. Inclusion of these costs will only widen the gap in the expected profits of lending to large and medium-sized enterprises and to SMEs. As a result, it could lead SMEs to self-select out of the credit market at lower rates of interest.),

$$E\pi(\overline{L}, \overline{C}, \overline{r} | G_2, p_2) - E\pi(\overline{L}, \overline{C}, \overline{r} | G_1, p_1) \geq 0. \tag{5}$$

First of all, it is easy to demonstrate that expected bank profits are greater on loans to enterprises with higher capital appreciation capacity when average project success probability is held constant across enterprises. In other words, suppressing the notation indicating the fixed contract terms,

$$E\pi(|G_2, \overline{p}) - E\pi(|G_1, \overline{p}) \geq 0, \tag{6}$$

where, $G_2 \geq G_1$.

Secondly, expected bank profits are greater on loans to enterprises with higher average project success probability when capital appreciation capacity is held constant across enterprises,

$$E\pi(|\overline{G}, p_2) - E\pi(|\overline{G}, p_1) \geq 0, \tag{7}$$

where, $p_2 > p_1$.

This latter proposition can be demonstrated by substituting in the expression for expected bank profits given fixed contract terms $\overline{L}, \overline{C}, \overline{r}$,

$$\begin{aligned} &\left[p_2\overline{L}(1+\overline{r}) + (1-p_2)\delta\overline{C} - f(\eta,\sigma) - \overline{L}(1+\mu)\right] \\ -&\left[p_1\overline{L}(1+\overline{r}) + (1-p_1)\delta\overline{C} - f(\eta,\sigma) - \overline{L}(1+\mu)\right], \end{aligned} \tag{8}$$

which is non-negative by condition (3), therefore, the above conclusion can be obtained.

The initial proposition of the differential expected bank profits of loans to enterprises of different sizes can now be seen by rewriting (5) as:

$$[E\pi(|G_2, p_2) - E\pi(|G_2, p_1)] + [E\pi(|G_2, p_1) - E\pi(|G_1, p_1)]. \tag{9}$$

by (6) and (7), both expressions in square brackets are positive, so that expected bank profits are in fact higher on large and medium-sized enterprises if contract terms are identical. Therefore, we have the following proposition:

Proposition 1. *With other things being equal, the average success probability of SMEs' projects is lower than that of large and medium-sized enterprise, and once successful, the average return of SMEs' projects is less than that of large and medium-sized enterprise. As a result, expected bank profits are higher on loans to large and medium-sized enterprises than on loans to SMEs.*

However, when loan demand is greater than supply, banks will choose from borrowing enterprises that, for any given contract terms, will yield the highest risk-adjusted expected net return. To select such enterprises, banks will compare: (1) cost of granting loans to enterprises of different sizes; (2) difference in expected returns across these enterprises that banks consider to be equally risky; and (3) differences in risks and willingness to pay across these enterprises that banks consider to be of equal expected returns. Therefore, it is just these flaws in SMEs themselves put them in a disadvantaged place in credit markets. In the following two parts, we analyzed the signaling mechanism of borrowing enterprises and the screening mechanism of banks before and after the loan issuance.

4. Signaling and Screening Mechanism before Lending

Before the loan transaction, borrowing enterprises send signals to banks by selecting contract terms, which can reflect their risk preference and level of credibility. And banks screen borrowing enterprises by making incentive compatible contract terms based on profit maximization principle. This section analyzed borrowing enterprises' signaling mechanism and banks' screening mechanism under ex-ante information asymmetry.

4.1. Conditions for Banks to Grant Loans to Enterprises

Bank loans should meet the following constraint:

$$E\pi = p_i L(1+r) + (1-p_i)\delta_i C - f(\eta, \sigma) - L(1+\mu) \geq 0 \tag{10}$$

In the equilibrium of competitive credit markets, expected bank profit is 0, thus we assume that expected bank profits on any loan are constant at 0. Differentiating expression (10) according to the implicit function derivation rule, the marginal substitution rate between the interest rate and the collateral requirement is

$$\frac{dr}{dC} = -\delta \frac{1-p_i}{p_i L} < 0 \tag{11}$$

Differentiating (11) with respect to p_i, we have

$$\frac{d}{dp_i}[\frac{dr}{dC}] = \frac{\delta}{L}\frac{1}{p_i^2} > 0 \tag{12}$$

Differentiating (10) with respect to p_i, we have

$$\frac{dE\pi}{dp_i} = L(1+r) - \delta C > 0 \tag{13}$$

According to expression (11) and (12), we get the iso-expected profit curve of the bank for collateral C and interest rate r $--\overline{E\pi}(L, C, r)--$ when the credit market is in equilibrium, as shown in Figure 1.

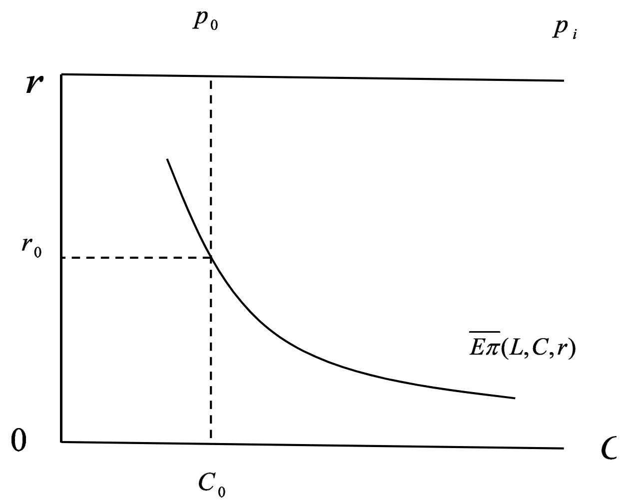


Figure 1. The iso-expected profit curve of the bank. Where, r: interest rate; C: collateral requirement; p_i: average success probability of group i's project; $\overline{E\pi}(L, C, r)$ the iso-expected profit curve of the bank for collateral c and interest rate r when the credit market is in equilibrium; r_0: credit rationing equilibrium interest rate; C_0: collateral requirement corresponding to r_0 on the iso-expected profit curve; p_0: borrowing enterprise's project success probability corresponding to r_0 on the iso-expected profit curve.

As we can see from Figure 1, the slope of $\overline{E\pi}(L, C, r)$ increases gradually with the increase of collateral requirement C and the decrease of interest rate r, which indicate that the slope of $\overline{E\pi}(L, C, r)$ increases with the project success probability of borrowing enterprises. Therefore, in equilibrium, banks are willing to provide low-interest rate and high collateral requirement contracts for enterprises with higher project success probability, while providing high-interest rates and low collateral requirement contracts for enterprises with lower project success probability.

In the light of theorem 1, theorem 2 and theorem 5 in the paper of Stiglitz, Weiss (1981) [3], we can see that, under information asymmetry, as the interest rate exceeds the credit rationing equilibrium interest rate r_0, expected bank profit of each loan will decrease with the interest rate. Therefore, as the interest rate $r > r_0$, expected bank profit must be less than that on the iso-expected profit curve in equilibrium. Suppose the collateral requirement corresponding to r_0 on the iso-expected profit curve is C_0, and the corresponding project success probability of the borrowing enterprise is p_0, then in equilibrium, on the iso-expected profit curve, expected bank profit must satisfy the condition that $C \geq C_0$. That is, in Figure 1, any point lies in the region where $C < C_0$ will not be a loan contract designed by banks for borrowing enterprises. Since expected bank profit in equilibrium is 0, according to formula (1), the expression of C_0 is

$$C_0 = \frac{L(1+\mu) + f(\eta, \sigma) - p_0(1+r_0)}{(1-p_0)\delta} \tag{14}$$

where, C_0 is the minimum collateral value for banks to screen borrowing enterprises. However, since the asset size of the borrowing enterprise needs to meet the condition $W_i - C_i > 0$, as a result, the amount of collateral provided by the enterprise that $W_i < C_0$ is limited by the total amount of its collateralizable assets, hence C_0 is also the critical asset size of enterprises entering credit market. Nevertheless, as we've expounded before, the asset size of SMEs are smaller than that of large and medium-sized enterprises, consequently, due to lack of collateralizable assets, SMEs are more likely to be suffered from credit rationing.

In addition, since for banks, there is a cost of making a loan, so there is a break-even point in the loan size, that is, there are a minimum loan size and a capital preservation interest profit. According to condition (10) and holding other variables constant, we have

$$L_0 = \frac{(p_i - 1)\delta C + f(\eta, \sigma)}{p_i(1+r) - \mu - 1} \tag{15}$$

$$L \geq L_0 \tag{16}$$

where L_0 represent the minimum loan size of a single loan of banks, rL_0 is the capital preservation interest profit of banks. However, for SMEs, their capital demand size tend to be lower, generally smaller than the critical loan size of banks, banks obtain relatively low profits from such enterprises, as a result, banks are reluctant to lend to SMEs. To sum up, we have the following proposition:

Proposition 2. *Borrowing enterprises whose initial asset size below the critical collateral value are unable to transmit their risk levels and borrowing enterprises whose loan size below the minimum loan size cause higher costs to banks. But SMEs tend to have lower initial asset size and tend to borrow less, which could not meet the profit maximization goal of banks, therefore, they are more likely to be suffered from credit rationing.*

4.2. Conditions for Enterprises to Apply for Loans

Borrowing enterprise should meet the following constraints in applying for a loan:

$$\rho = p_i U[G_i(K) - L(1+r) + W_i] + (1 - p_i)U[W_i - (1+\xi)C] - U(W_i) \geq 0 \tag{17}$$

Differentiating expression (17) according to the implicit function derivation rule, borrowing enterprise's marginal substitution rate between the interest rate and the collateral requirement is

$$\frac{dr}{dC} = -\frac{(1+\xi)(1-p_i)U'[W_i - (1+\xi)C]}{Lp_i U'[G_i(K) - L(1+r) + W_i]} < 0 \tag{18}$$

Differentiating (18) with respect to p_i, we have

$$\frac{d}{dp_i}[\frac{dr}{dC}] = \frac{(1+\xi)U'[W_i - (1+\xi)C]}{Lp_i^2 U'[G_i(K) - L(1+r) + W_i]} > 0 \tag{19}$$

According to inequality (18), r varies inversely with C, which indicates that, for any borrowing enterprise, they are willing to pay lower interest rate when banks demand higher collateral, while they are willing to offer less collateral when banks demand higher interest rate. As $p_1 < p_2$, we have $\frac{d}{dp_1}[\frac{dr}{dC}] < \frac{d}{dp_2}[\frac{dr}{dC}]$, that's to say, compared with SMEs, large and medium-sized enterprises are willing to offer more collateral in exchange for bank's interest concessions, because they are more likely to recover their collateral. However, SMEs with higher average risks are just the opposite case.

4.3. The Influence of Each Variable on Expected Bank Profits

We've analyzed the influence of borrowing enterprises' risk level and capital appreciation capacity on expected bank profits. Now we continue to discuss the impact of other variables on expected bank profits and how these impacts affect the credit availability of borrowing enterprises.

4.3.1. The Proportion of Public Property Rights of Borrowing Enterprises

Differentiating $E\pi$ with respect to η and according to the condition that $f'(\eta) < 0$, we have

$$\frac{\partial E\pi}{\partial \eta} = -f'(\eta) > 0 \tag{20}$$

That is to say, expected bank profits vary directly with the proportion of borrowing enterprise's public property rights, that is, the higher the proportion of borrowing enterprise's public property rights, the higher the expected bank profits. However, public property rights of SMEs have are generally low. Therefore, private property rights is an extremely significant factor that affects the credit availability of SMEs in developing countries.

4.3.2. The Degree of Information Asymmetry between Banks and Borrowing Enterprises

Differentiating $E\pi$ with respect to σ and according to the condition that $f'(\sigma) > 0$, we have

$$\frac{\partial E\pi}{\partial \sigma} = -f'(\sigma) < 0 \tag{21}$$

Which means that, expected bank profits vary inversely with the degree of information asymmetry between borrowing enterprises and banks, that is, the higher the degree of information asymmetry between borrowing enterprises and banks, the lower the expected bank profits. However, compared with large and medium-sized enterprises, there is generally a greater degree of information asymmetry between SMEs and banks, so the degree of information asymmetry between enterprises and banks is another important factor that affects the credit availability of SMEs in developing countries.

4.3.3. Different Types of Collateral

As we've noted before, the core competitiveness of SMEs is manifested in intangible assets, thus lack collateralizable fixed assets for financing. What would happen to SMEs if they rely on intangible assets to apply for loans?

Suppose borrowing enterprises can be divided into two groups according to the types of their collateralizable assets, one group uses intangible assets as collateral, the other group uses traditional tangible assets as collateral (denoted by i = 1, 2 respectively). Assume that for given contract terms (L, C, r), their assets realization ratio of the collateral are δ_1, δ_2 respectively. Owing to the fact that compared with traditional tangible collateral, the loan trading market with intangible assets as collateral is not very perfect yet, the process of disposal and realization of intangible assets is very complicated, banks face many obstacles in getting loan repayment by disposing of intangible assets, it is difficult for banks to recover funds timely by means of asset auctions, leases, transfers, etc. Therefore, we assume that $\delta_1 < \delta_2$.

Differentiating $E\pi$ with respect to δ_i, we have

$$\frac{\partial E\pi}{\partial \delta_i} = (1 - p_i)C > 0, \tag{22}$$

which indicate that, the higher the assets realization ratio of the collateral, the higher the expected bank profits. However, for two types of collateral with the same risk level, $\delta_1 < \delta_2$, as a result, $E\pi_1 < E\pi_2$, consequently, banks are more willing to lend to borrowing enterprises that provide traditional tangible collateral.

In the actual loan business, value determination cost and assets realization ratio of the traditional tangible collateral (such as land, real estate, machinery equipment etc.) are relatively stable, for banks that lack experience in intangible asset lending, the variance in the assets realization ratio of collateral $\delta_1 - \delta_2$ and the difference in expected bank profits $E\pi_1 - E\pi_2$ are even greater. This partly explains that, when borrowing enterprise uses intangible assets as collateral, even they have good reputation and profitability, most inexperienced banks still choose to lend to borrowing enterprises who can provide traditional tangible collateral, which lead to more serious credit rationing, and it is more difficult for SMEs to obtain credit funds. In summary, we have the following proposition:

Proposition 3. *Compared with large and medium-sized enterprises, SMEs lack tangible assets as collateral, have a lower proportion of public property rights, and exists a greater degree of information asymmetry with banks, all these factors resulting in lower expected bank profits, thus exacerbating credit rationing in SMEs.*

5. Moral Hazard Inhibition Mechanism after Lending

After a borrowing enterprise obtains a loan, it may also have "moral hazard" problem because of bank's inability to supervise its behavior, this problem may be manifested in the transfer of credit funds from the project to non-productive uses. The investment decision made by the enterprise after obtaining loans will affect the project success probability and the expected enterprise returns, thus affect the expected bank profits, this stage of decision embodies the incentive effect. Considering this moral hazard problem caused by the ex-post asymmetric information, banks would impose stricter credit rationing on borrowing enterprises ex-ante. In this section, we assume that borrowing enterprises can freely allocate the credit funds they receive between production and consumption purposes, and then we have explained how this autonomy affects the behavior of borrowing enterprises and, in turn, the credit decisions of banks.

5.1. Incentive Effects of Borrowing Enterprises

Assume that risk-neutral borrowing enterprise chooses to invest K in the project, which is less than the loan size, L, that is, the amount of credit $L-K$ will be transferred by the borrowing enterprise for consumption uses. The expected utility of the borrowing enterprise is the sum of the utility of the credit diversion $L-K$ plus the utility of the investment return ρ. Given loan contract terms, borrowing enterprise's optimization problem is to choose the funds K invested in the project to satisfy

$$\begin{aligned} &\max_K \{U(L-K)+\rho\}, \\ s.t.& \\ &eq.(2), \\ &K \le L. \end{aligned} \tag{23}$$

For this optimization problem, by Lagrange multiplier method, we have the following first-order condition:

$$p_i U'[G_i(K)-L(1+r)+W_i]G'(K) \ge U'(L-K) \tag{24}$$

where $K=L$ if the strong inequality holds.

Denote the solution to this problem as $K*(r)$, as (24) shows, $K*(r)$ is selected by comparing the expected marginal return to investing borrowed funds in the project with their marginal utility of funds for consumption uses. No analytically useful expression can be given for conditions under which the solution to (23) is an interior maximum and diversion of credit to consumption uses occurs (i.e., $K* < L$). Nonetheless, given contract conditions, as K approaches L, expected enterprise utility is almost certainly concave in K, and may be decreasing. (Differentiation of the first order condition (24) with respect to K yields $p_i U'[G_i(K)-L(1+r)+W_i]G''(K) < 0$. Thus, the expected enterprise return has a concave portion with respect to K, and has a turning point.)

Now we can see the incentive effect of raising interest rates on the behavior of borrowing enterprise. As r increases, the level of average success probability p_i and average project return in the event of success $G_i(K)$ needed for the enterprise to repay the loan increases, expected returns to investment subsequently decline, and as the left-hand side of condition (24) decreases, incentives for credit diversion increase. Actual credit diversion will increase if the solution to (23) is, or becomes, an interior one. Other things equal, increased credit diversion will decrease $G_i(K)$ and expected bank profits. However, banks can diminish incentive effects by restricting loan size so that marginal returns to investment funds $G_i{}'(K)$ remain high.

5.2. Credit Rationing in SMEs under Incentive Effects

The above analysis shows that, from the bank's point of view, as the interest rate increases, borrowing enterprise autonomy in credit use can cause average borrowing enterprises characteristics to worsen. Banks in our model face a situation similar to that in the Stiglitz-Weiss model. After some critical interest rates r_i*, expected bank profits per loan to borrowing enterprise in the group i begin to decrease in r. So how does this functional relationship affect the credit market equilibrium?

Even if banks treat all borrowing enterprises as identical if there is excess demand for loans at $r*$, it would be better for banks to arbitrarily rations credit to borrowing enterprises at $r*$ than if it raises the interest rate to eliminate the excess demand. At interest rates $r*$ where excess credit demand exists, banks can still make the same amount of loans that it could at a higher interest rate. Average bank profits per loan made will be higher at $r*$ even though banks arbitrarily select borrowing enterprises to grant loans. In other words, banks would find it profit maximizing to impose an interest rate restriction.

However, in general, banks can distinguish between large and medium-sized enterprise group and SMEs group, and have transaction records of each large and medium-sized enterprise, thus could design specific credit contracts for large and medium-sized enterprises, so the problem of credit rationing in large and medium-sized enterprises would disappear. It has been proved that for given contract terms, expected bank profits on loans to large and medium-sized enterprises exceeds that to SMEs. Even if the incentive effect were identical on large and medium-sized enterprises and SMEs (i.e., $r_1* = r_2*$), this differential expected profitability alone could cause SMEs to be eliminated from the credit market. As shown in Figure 2, at the endogenous interest rate ceiling of $r*$, it would always be more profitable to lend to large and medium-sized enterprises. Only after the interest rate had been lowered to $\hat{r}$, and all large and medium-sized enterprises desiring loans at $\hat{r}$ had been given credit, would it be possible for any SME to receive credit.

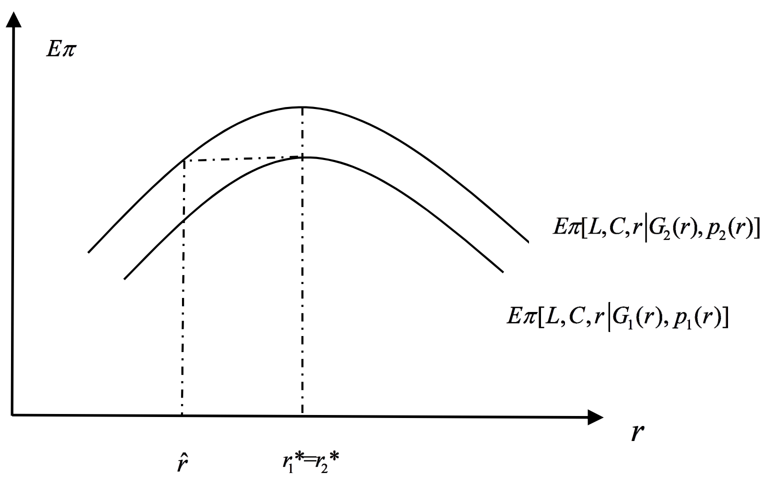


Figure 2. Endogenous interest rate restrictions and equilibrium credit rationing. (Where, r: interest rate; $E\pi$: expected bank profit; $E\pi[L, C, r|G_1(r), p_1(r)]$: expected bank profits on loans to SMEs; $E\pi[L, C, r|G_2(r), p_2(r)]$: expected bank profits on loans to large and medium-sized enterprises; r_1*: interest rate that maximizes expected bank profits on loans to SMEs; r_2*: interest rate that maximizes expected bank profits on loans to large and medium-sized enterprises; $\hat{r}$: interest rate that lower than r_1* and r_2*.).

In fact, the situation is likely to be even less favorable for SMEs than Figure 2 shows. Because funds available for self-consumption is likely to be relatively lower on SMEs, incentives for credit diversion are likely to be even higher. Greater risk and output variability on SMEs would further heighten relative SMEs adverse incentive effects. More severe incentive effects on loans to SMEs would imply that per-loan expected profits begin to diminish at a lower interest rate on SMEs ($r_1* < r_2*$),

Figure 3 illustrates this situation. At best, in an adverse incentive constrained equilibrium, SMEs will now only be rationed credit after all large and medium-sized enterprises desiring credit at interest rate $\hat{r}'$ receive loans. For a given opportunity cost and supply of loanable funds, it becomes more likely that SMEs will be completely rationed out from formal credit markets.

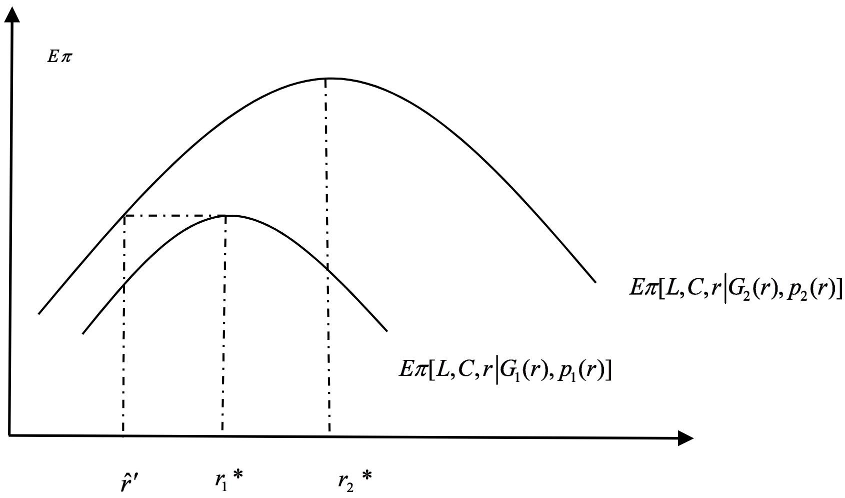


Figure 3. Credit rationing when incentive effects are more severe on SMEs.

Above all, we have the following proposition:

Proposition 4. *Compared with large and medium-sized enterprises, SMEs at lower living standards (with higher $U'(L-K)$) have a stronger incentive to increase current consumption at the expense of future investment returns. With other things being equal, increased credit diversion will decrease borrowing enterprise's project expected returns and thus decrease expected bank profits. Considering this, banks will apply stricter credit rationing to reduce this incentive effect, thus making the financing constraints of SMEs more severe.*

6. Conclusions and Remarks

Although there has been substantial research on the problem of borrowers' financing constraints at home and abroad, the enterprises' size has not been taken into account yet. The research on the causes of financing barriers of SMEs is not systematic and deep enough. In order to explain the formation mechanism of credit rationing in SMEs, by considering the differences between SMEs and large and medium-sized enterprises in terms of their project success probability and capital appreciation ability, we have established a comprehensive credit rationing model of endogenous enterprise size. And by considering banks' screening principles before and after the loan approval, this paper systematically analyzed the internal mechanism of credit rationing in SMEs.

The conclusion shows that, the main reason why it is more difficult for SMEs to obtain credit funds in the formal credit market lies in that, before approving the loan, SMEs are unable to transmit their risk levels, as their initial asset size are generally below the critical collateral value, and loan to SMEs cause higher costs to banks, as their loan size are generally below the minimum loan size. SMEs also lack tangible assets as collateral, exists a lower proportion of public property rights, and have a greater degree of information asymmetry with banks. Besides, after approving the loan, SMEs at lower living standards have a stronger incentive to increase current consumption at the expense of future investment returns, which would decrease borrowing enterprise's project expected returns. All these factors resulting SMEs loan less profitable for banks, considering this, the rational choice of profit maximization banks is to ration credit on SMEs.

This kind of credit market equilibrium reduced the allocation efficiency of credit resources and distorted the Pareto optimization of the whole society. Ration credit on SMEs with relatively high productivity and relatively low risk hampered the use of credit, and other things equal, distorted equilibrium credit allocation away from SMEs.

This study has important implications, especially for banks and governments. According to the results of the theoretical analysis, in order to correct this distortion phenomenon and fundamentally solve the credit rationing problem, thereby increasing the credit availability of SMEs and improve the sustainability of credit market's stable development. On one hand, being able to analyze and predict market and customer behavior with Big Data is a new paradigm shift for SMEs [43]. The core features of big data can be characterized by "volume, velocity, variety" [44]. Using credit technology based on big data, commercial banks can efficiently analyze more than trillion bytes of relevant information, which can improve the loan approval efficiency and reduce the degree of information asymmetry between SMEs and banks. Therefore, banks should use big data to carry out credit technology innovation, based on the quantitative information which resides in the bank management information system to predict risk and identify loan applicants, instead of making credit decisions based on the qualitative characteristics of loan applicants.

On the other hand, the failure of the market to solve the problem provides a justification for government intervention. The aim of government support for SMEs is to ultimately establish, without governmental financial aid, viable, competitive, and innovative SMEs [45]. Governments can provide a variety of support services for SMEs. These include provisions for targeted and quality business support services; immediate, technical, and managerial training programs; the cutting of administrative costs and burdens of SMEs; building network cross sectors and cross borders; provisions for financial incentives and assistance; and legal framework reinforcement [46,47]. The government can also compensate banks for risk losses, and banks grant loans to SMEs. These measures can increase the credit availability of SMEs, thus alleviate the financing constraints of SMEs. Therefore, the sustainability of the national economy and the healthy development of SMEs need the joint efforts of all parties.

This study presents some limitations. First, in the analysis of moral hazard inhibition mechanism after lending, we assume that borrowing enterprises are all risk-neutral, in fact, we can prove that even if borrowing enterprises are assumed to be risk averse, banks still potentially face adverse incentive and selection effects, thus we can obtain the same conclusions as in risk-neutral situations. Future research can discuss this situation in detail. In addition, this paper theoretically analyzed the formation mechanism of credit rationing in SMEs, but all the propositions have not been tested empirically. Future research can use credit data from enterprises and banks for empirical testing. These data can be obtained from bank financial statements and questionnaires on borrowing enterprises.

Author Contributions: Y.J. and S.Z. conceived and designed the model; Y.J. analyzed the theory; S.Z. contributed reagents/materials/analysis tools; Y.J. wrote the paper.

Funding: Policy Research on accelerating the implementation of innovation driven development strategy in Shaanxi Province: 2016KRZ003.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

1. Baumol, W.J. Entrepreneurship in Economic Theory. *Soc. Sci. Electron. Publ.* **2009**, *58*, 64–71.
2. Servon, L.J. *Bootstrap Capital: Microenterprises and the American Poor*; Brookings: Washington, DC, USA, 1999.
3. Stiglitz, J.E.; Weiss, A. Credit Rationing in Markets with Imperfect Information. *Am. Econ. Rev.* **1981**, *71*, 393–410.
4. Beck, T.; Aslı, D.K.; Maksimovic, V. Financial and legal constraints to growth: Does firm size matter? *J. Financ.* **2005**, *60*, 41. [CrossRef]
5. Zott, C.; Amit, R. Business model design and the performance of entrepreneurial firms. *Organ. Sci.* **2007**, *18*, 181–199. [CrossRef]

6. Halme, M.; Korpela, M. Responsible innovation toward sustainable development in small and medium-sized enterprises: A resource perspective. *Bus. Strategy. Environ.* **2014**, *23*, 547–566. [CrossRef]
7. Uhlaner, L.M.; Berent-Braun, M.M.; Jeurissen, R.J.; de Wit, G. Beyond size: Predicting engagement in environmental management practices of Dutch SMEs. *J. Bus. Ethics* **2012**, *109*, 411–429. [CrossRef]
8. Stock, G.N.; Greis, N.P.; Fischer, W.A. Firm size and dynamic technological innovation. *Technovation* **2002**, *22*, 537–549. [CrossRef]
9. Walker, H.; Preuss, L. Fostering sustainability through sourcing from small businesses: Public sector perspectives. *J. Clean. Prod.* **2008**, *16*, 1600–1609. [CrossRef]
10. Widya-Hasuti, A.; Mardani, A.; Streimikiene, D.; Sharifara, A.; Cavallaro, F. The Role of Process Innovation between Firm-Specific Capabilities and Sustainable Innovation in SMEs: Empirical Evidence from Indonesia. *Sustainability* **2018**, *10*, 2244. [CrossRef]
11. Gou, Q.; Huang, Y. Access to the determinants of credit rationing: evidence from Chinese firms. *J. Financ. Res.* **2014**, *8*, 1–17.
12. Demirguckunt, A.; Ayyagari, M.; Maksimovic, V. How important are financing constraints? The role of finance in the business environment. *Policy Res. Work. Pap.* **2010**, *22*, 483–516.
13. Beck, T.; Demirgüç-Kunt, A.; Laeven, L.; Maksimovic, V. The determinants of financing obstacles. *J. Int. Money Financ.* **2006**, *25*, 932–952. [CrossRef]
14. Beck, T.; Demirguc-Kunt, A.; Maksimovic, V. Bank Competition and Access to Finance: International Evidence. *J. Moneycreditand Bank.* **2004**, *36*, 627–648. [CrossRef]
15. Levonian, M.; Jennifer, S. *Small Banks, Small Loans, Small Business*; FRBSF Weekly Letter: San Francisco, CA, USA, 1996; pp. 96–102.
16. Peek, J.; Rosengren, E.S. Small Business Credit Availability: How Important Is the Size of the Lender? In *Universal Banking: Financial System Design Reconsidered*; Anthony, S., Ingo, W., Eds.; Irwin Publishing: Burr Ridge, IL, USA, 1996.
17. Rajan, P.R.G. The Benefits of lending relationships: Evidence from small business data. *J. Financ.* **1994**, *49*, 3–37.
18. Baltensperger, E. Credit rationing: Issues and questions. *J. Money Credit Bank.* **1978**, *10*, 170–183. [CrossRef]
19. Yang, H. Research on the financing dilemma and countermeasures of small and micro enterprises in China. Ph.D. Thesis, Anhui University, Hefei, China, 2012.
20. Demirgüç-Kunt, A.; Maksimovic, V. Law, finance, and firm growth. *J. Financ.* **1998**, *53*, 2107–2137. [CrossRef]
21. Laeven, L. Does financial liberalization reduce financing constraints? *Financ. Manag.* **2003**, *32*, 5–34. [CrossRef]
22. Gelos, G.; Werner, A. Financial liberalization, credit constraints, and collateral: investment in the Mexican manufacturing sector. *J. Dev. Econ.* **2002**, *67*, 1–27. [CrossRef]
23. Coase, R.H. The nature of the firm. *Economica* **1937**, *4*, 386–405. [CrossRef]
24. Williamson, O. *Markets and Hierarchies: Analysis and Antitrust Implications*; Free Press: New York, NY, USA, 1975.
25. Williamson, O. *The Economic Institutions of Capitalism*; Free Press: New York, NY, USA, 1986.
26. Klein, B.; Crawford, R.G.; Alchian, A.A. Vertical integration, appropriable rents, and the competitive contracting process. *J. Law Econ.* **1978**, *21*, 297–326. [CrossRef]
27. Grossman, S.J.; Hart, O.D. The costs and benefits of ownership: A theory of vertical and lateral integration. *J. Polit. Econ.* **1986**, *94*, 691–719. [CrossRef]
28. Guan, J.C. Comparison study of industrial innovation between China and some European countries. *Prod. Invent. Manag. J.* **2002**, *43*, 30–46.
29. Guan, J.C.; Yam, R.C.M.; Tang, E.P.Y.; Lau, A.K.W. Innovation strategy and performance during economic transition: evidences in Beijing, China. *Res. Policy* **2009**, *38*, 802–812. [CrossRef]
30. Guan, J.C.; Yam, R.C.M. Effects of government financial incentives on firms' innovation performance in China: Evidences from Beijing in the 1990s. *Res. Policy* **2015**, *44*, 273–282. [CrossRef]
31. Dang, C.; Li, Z.F.; Yang, C. Measuring Firm Size in Empirical Corporate Finance. *J. Bank. Financ.* **2018**, *86*, 159–176. [CrossRef]
32. Smyth, D.J.; Boyes, W.J.; Peseau, D.E. The measurement of firm size: Theory and evidence for the United States and the United Kingdom. *Rev. Econ. Stat.* **1975**, *57*, 111–114. [CrossRef]

33. Chan, Y.S.; Kanatas, G. Asymmetric Valuations and the Role of Collateral in Loan Agreements. *J. Money Credit Bank.* **1985**, *17*, 84–95. [CrossRef]
34. Atieno, R. *Formal and Informal Institutions Lending Policies and Access to Credit by Small-scale Enterprises in Kenya: An Empirical Assessment*; Research Paper 111; African Economic Research Consortium: Nairobi, Kenya, 2001.
35. Aziz, J. Growth-Financial Intermediation Nexus in China. *Imf. Work. Paper.* **2006**, *2*, 194. [CrossRef]
36. Belongia, M.T.; Gilbert, R.A. The effects of federal credit programs on farm output. *Am. J. Agric. Econ.* **1986**, *72*, 769–773. [CrossRef]
37. Hughes, A. *On Enlarging Employment by Promoting Small Enterprises*; Working Paper No. 180; ESRC Centre for Business Research, University of Cambridge: London, UK, 2000.
38. Karnani, A. Microfinance misses its mark. *Retriev. Febr.* **2007**, *18*, 2009.
39. Kellogg, C. Evaluating poverty outreach of small business lending: a study of BRAC Bank, Bangladesh. *Enterp. Dev. Microfinanc.* **2009**, *20*, 188–204. [CrossRef]
40. Banerjee, A.V.; Duflo, E.; Glennerster, R.; Kinnan, C. The Miracle of Microfinance? Evidence from a Randomized Evaluation. *Ssrn. Electron. J.* **2015**, *7*, 22–53. [CrossRef]
41. Banerjee, A.V.; Duflo, E. Do Firms Want to Borrow More? Testing Credit Constraints Using a Directed Lending Program. *Soc. Sci. Electric. Publish.* **2008**, *81*, 572–607.
42. Lin, Y.; Li, Y. Promoting the growth of medium and small-sized enterprises through the development of medium and small-sized financial institutions. *Econ. Res. J.* **2001**, *1*, 10–18.
43. Sen, D.; Ozturk, M.; Vayvay, O. An Overview of Big Data for Growth in SMEs. *Procedia—Soc. Behav. Sci.* **2016**, *235*, 159–167. [CrossRef]
44. Jin, X.; Wah, B.W.; Cheng, X.; Wang, Y. Significance and challenges of big data research. *Big Data Res.* **2015**, *2*, 59–64. [CrossRef]
45. OECD. *Small and Medium-sized Enterprises in Turkey: Issues and Policies*; OECD: Paris, France, 2004.
46. Doh, S.; Kim, B. Government support for SME innovations in the regional industries: The case of government financial support program in South Korea. *Res. Policy* **2014**, *43*, 1557–1569. [CrossRef]
47. Wilson, K. Encouraging the Internationalisation of SMEs. In *Promoting Entrepreneurship in South East Europe: Policies and Tools*; Potter, J., Proto, A., Eds.; OECD: Paris, France, 2007; pp. 43–66.

Annex 547

E. Kemp-Benedict et al., “Climate Impacts on Capital Accumulation in the Small Island State of Barbados”, *Sustainability*, 2019

sustainability

MDPI

Article

Climate Impacts on Capital Accumulation in the Small Island State of Barbados

Eric Kemp-Benedict [1,*], Jonathan Lamontagne [2], Timothy Laing [3] and Crystal Drakes [4]

1. US Center, Stockholm Environment Institute, Somerville, MA 02144, USA
2. Department of Civil and Environmental Engineering, Tufts University School of Engineering, Science & Engineering Complex, Anderson Hall, Medford, MA 02155, USA; Jonathan.Lamontagne@tufts.edu
3. Brighton Business School, University of Brighton, Mithras House, Lewes Road, Brighton BN2 4AT, UK; T.J.Laing@brighton.ac.uk
4. BlueGreen Initiative Inc., Peterkin Road, St. Michael, Barbados; crystal.drakes@bluegreeninitiative.org

* Correspondence: eric.kemp-benedict@sei.org

Received: 9 May 2019; Accepted: 4 June 2019; Published: 7 June 2019

check for updates

Abstract: This paper constructs a model of climate-related damage for small island developing states (SIDS). We focus on the loss of private productive capital stocks through extreme climate events. In contrast to most economic analyses of climate impacts, which assume temperature-dependent damage functions, we draw on the engineering literature to allow for a greater or lesser degree of anticipation of climate change when designing capital stocks and balancing current adaptation expenditure against future loss and damage. We apply the model to tropical storm damage in the small island developing state of Barbados and show how anticipatory behavior changes the damage to infrastructure for the same degree of climate change. Thus, in the model, damage depends on behavior as well as climate variables.

Keywords: climate change; adaptation; loss and damage; damage function; return period; tropical cyclone

JEL Classification: O11; Q01

1. Introduction

Small island developing states (SIDS) are expected to be among the most heavily impacted by climate change [1], including sea level rise, cyclones, rising temperatures, and changing rainfall patterns [2]. While many small island economies perform comparatively well [3], arguably because they must be open to trade due to their narrow resource and export bases [4], their reliance on exports contributes to fluctuations in growth and recurrent high debt levels [5]. The combination of economic and climate vulnerability suggests that understanding climate-economy interactions is particularly important for SIDS. Yet, because of the limited data for most small islands, there have been few studies, particularly those that treat the economy as a whole (the recent study by Moore et al. [6] being a rare exception).

Most economic analyses of climate impact are carried out with global integrated assessment models (IAMs) that combine greenhouse gas emissions from economic activity with a representation of the climate system. Some IAMs, such as DICE [7,8] and FUND [9], as well as the post-Keynesian model developed by Rezai et al. [10], include feedback from the climate system to the economy. Both DICE and FUND implement a cost-benefit analysis and compute optimal emissions trajectories, given their assumptions about social preferences (an optimization mode). Other IAMs, such as GCAM [11,12], can also be run in a simulation mode for exploring alternative non-optimal scenarios. The IAMs that compute climate damage assume a "damage function" that depends on global mean temperature [13]. While most are aggregate, the FUND model takes a disaggregated approach, with separate damage functions for different kinds of climate impacts [14,15]. Each damage function depends on the global climate (either global temperature or greenhouse gas concentration) and the average income.

This paper develops a sub-global simulation model that includes both climate damage and economic sub-models. It is applied to a national scale but could also be applied to a regional scale. The economic sub-model is structuralist [5,16,17], which makes it similar to the post-Keynesian model by Rezai et al. [10], but different from, for example, the DSGE model presented in [18] or the neoclassical FUND and DICE models. The goal for the climate damage sub-model is to represent the loss of productive capital through extreme climate events, whereby, "productive capital" represents the physical stocks used to produce goods and services for sale, as opposed to non-commercial capital, non-productive commercial capital (such as protective structures) and public infrastructure.

We depart from both FUND and DICE by proposing a behaviorally-motivated model for climate damage, rather than a parameterized model. This is useful for simulation, because it allows for a richer set of alternative scenarios and policy options by targeting specific behavioral rules. In this paper, we focus on how anticipation of climate damage affects adaptation expenditure, but extensions of the model could introduce additional behaviors, such as different degrees of recovery after disaster. Furthermore, we differ from FUND and DICE by representing climate damage to capital stocks rather than as a loss in GDP. As noted by Piontek et al. [19], loss of inputs to production have different effects than loss of outputs. The inclusion of adaptive behaviors and the loss of physical capital also distinguishes the study from that of Moore et al. [6], who applied RICE, the regional version of the DICE model, to a study of climate impacts in the Caribbean. Moore et al. employed a general equilibrium analysis, which contrasts both with partial equilibrium analyses, such as that of Strobl [20], and with the dynamic macroeconomic analysis carried out in this paper.

The loss of productive capital is admittedly one of many ways in which natural disasters affect societies and economic performance. There are humanitarian impacts, loss of inventory, disrupted supply chains, and damage to public infrastructure. Moreover, these impacts are unequally distributed, with particularly strong effects on poorer households, and are thereby likely to exacerbate poverty [21]. Indeed, at least in a large continental economy like the US, emigration of wealthy households from impacted communities has a measurable impact on the level of economic activity [22]. Nevertheless, damage to productive capital stocks ("capital stock shocks" see [19]) does occur, can be expected to affect long-term performance, and should be accounted for in growth models [23]. Moreover, under climate change, events that were rare under historical climate conditions are becoming more frequent, and they are expected to become even more common as the climate continues to change [24,25].

Our approach is seen as an extension of the temperature-dependent depreciation rate introduced by Fankhauser and Tol [26] or the greenhouse gas concentration-dependent depreciation rate used by Rezai et al. [10]. We ultimately derive a (sea-surface) temperature-dependent depreciation rate, but we start by considering the return period of tropical cyclones, rather than temperature, as the relevant climate variable. Return periods for certain types of events are calculable from climate model outputs [24,27,28], and are a conventional input into the design practices of civil engineers, particularly hydrologists concerned with flooding and storm damage [29,30]. Thus, our approach connects economic analysis under climate change to engineering practice.

In engineering design and risk assessment there is a need to relate the magnitude of an extreme event to its frequency. With public investment, this relationship enables engineers and planners to design infrastructure to efficiently utilize resources in a way that reflects societal values [29]. For commercial projects, it allows engineers to balance potential damage to productive capital (loss and damage) against adaptation costs.

1.1. Tropical Storm Impacts in the Caribbean and in the Barbados

Tropical cyclones, more commonly known in the Caribbean as hurricanes and tropical storms, have caused tens of thousands of deaths since records became available in the late 1880s. They have affected millions of lives and destroyed billions of dollars in property. Since the 1930s, storm intensity has not subsided, and populations have increased. Casualty rates have decreased due to increasingly effective mitigation measures and improved preparedness activities, yet property damage has risen, highlighting weaknesses in structural mitigation and adaptation measures [31].

Since 1995, there has been an increase in the intensity and distribution of hurricanes in the Caribbean. Increases in global temperature are expected to further intensify and increase the frequency of category 3–5 hurricanes. This poses a direct threat to small Caribbean states, which are mainly coastal communities [32]. From 1950–2014 the Caribbean has been impacted by a total of 581 tropical cyclones (298 tropical storms and 283 hurricanes) that either made landfall or passed within 69 miles of the Caribbean islands [33]. The 2017 Atlantic hurricane season was the third worst in history. Hurricanes Maria and Irma caused an estimated total economic damage of 220 billion USD [34] and affected many of the Caribbean islands including Dominica, Antigua and Barbuda, St. Maarten, Anguilla, the British Virgin Islands, and Puerto Rico. The value of infrastructure, buildings, and other capital stocks exceeded GDP, and in some instances the GDP loss in island states was over 100%, for example, Hurricane Maria damage loss totaled 224% of Dominica's GDP [35] and Hurricane Irma left the island of Barbuda uninhabitable for days.

Most tropical cyclones that pass through the Caribbean miss Barbados, which lies on the southern fringe of the hurricane belt. Nevertheless, Barbados is periodically affected by tropical storms and hurricanes. Since 2010, the island has been impacted by four tropical storm events and one trough system. The sovereign insurance payouts under the Caribbean Catastrophe Risk Insurance Facility (CCRIF) for this event totaled 18 million USD, with the highest payouts occurring in 2018 due to tropical storm Kirk (5.8 million USD), and in 2010 tropical cyclone Tomas (8.5 million USD). Losses and damages are affected by the degree of preparation in anticipation of a storm. Barbados expected modest impacts from tropical cyclone Tomas in 2010 and preparations were correspondingly modest. The impacts were much worse than anticipated, and resulted in the country's largest payout to date under CCRIF.

1.2. Model Probability Distributions

In this paper we focus on hydro-meteorological factors, specifically storms. Two approaches for modeling such events are generally used: annual maximum series (AMS) and peaks-over-threshold (POT) analyses [36]. In the AMS approach, a probability distribution is fit to the series of maximum events (e.g., flood or wind speed) in each year of the record. In the POT approach, only the magnitudes and arrivals of events exceeding a threshold are modeled using probability distributions. The POT methods capture the reality that multiple events of interest may occur in a single year, whereas no events of interest may occur in other years. The POT methods, however, typically require more data for calibration. In this paper we apply an AMS model, leaving the more complex POT analysis for future work.

The magnitude-frequency relationship is most often expressed in terms of the quantiles of the probability distribution assumed to approximate the behavior of a particular disaster type,

$$F_X(x_p) = p, \tag{1}$$

where, F_X is the cumulative distribution function (CDF) of random variable X, and x_p is the pth quantile of X, where $0 \leq p \leq 1$ is the non-exceedance probability of magnitude x_p over a particular time period, normally taken to be a year. This information is very often communicated in terms of the return period of an event of magnitude x_p, where the return period T is defined as the inverse of the exceedance probability,

$$T = \frac{1}{1-p} = \frac{1}{1-F_X(x_p)}. \tag{2}$$

If the distribution of the disaster magnitude is not changing, the return period can be interpreted in two ways: (1) if F_X describes the distribution of maximum observed event in a time period (say the maximum annual flood), then over T periods one expects (in the statistical sense of "expectation") for x_p to be exceeded exactly once; (2) if the realizations of X are independent from one time period to the next, then the return period is also the average waiting time to observe an event exceeding x_p.

1.3. Stationarity and Non-Stationarity

A crucial assumption behind the use of the return period is stationarity, meaning that the probability distribution of events remains unchanged over time. Stationarity has never held exactly in reality. Even in a stationary climate, land use change from human activity (e.g., de- and afforestation, urbanization, agricultural practices, etc.) can affect flood distributions in complex ways [37]. However, even when it is justified, the concept of a return period can be challenging for non-specialists to understand. The case for non-stationarity (e.g., [38]) should not be overstated, and for many analyzes stationarity remains a reasonable assumption. However, non-stationarity is both accelerating and amplifying due to climate change, and as it does, the meaning of the return period becomes problematic even for specialists [39–42]. Nevertheless, the return period remains a popular means of communicating the frequency-magnitude relationship of extreme events, and it was adopted in the IPCC special report on extreme events [24].

In this paper we allow for forward-looking design in that an engineer is assumed to choose the least-cost design given anticipated changes in the frequency of extreme events.

1.4. The Perpetual Inventory Model with Climate Damage

In the model developed in this paper, gross domestic output (GDP), which we denote by Y, is given by a capital productivity κ multiplied by the total capital stock,

$$Y_t = \kappa K_t. \tag{3}$$

While it would be helpful to distinguish different types of capital and their vulnerability, as in [43], data limitations prevent us from that level of analysis for our case study country of Barbados.

The change in the value of capital stock, K, is given by the value of gross investment, I, net of depreciation, D. The capital stock in period $t + 1$ is then calculated as

$$K_{t+1} = K_t + I_t - D_t. \tag{4}$$

The "perpetual inventory" method of accounting for capital stock is a common approach (e.g., it was used for the Penn World Tables [44]). It can be implemented in a straightforward way using data from national accounts, with the initial level of the capital stock as the only free parameter.

Depreciation can be expressed as a rate δ per unit of capital stock multiplied by the value of the capital stock. In practice, depreciation rates vary over time. However, in this paper we simplify the analysis by assuming a constant rate and we provide a justification in Section 2.5. With this assumption, we can write Equation (4) as

$$K_{t+1} = (1-\delta)K_t + I_t. \tag{5}$$

Our assumption of a constant depreciation rate is consistent with an assumption that climate change affects capital stocks only through extreme events. More gradual changes, such as rising sea levels leading to quicker erosion of sea defenses, are not considered in this model.

Extreme climate events lead to loss of capital beyond normal depreciation. Such events are random, and they appear in the model as a series of independent shocks. This should be a reasonable assumption for storms; droughts, in contrast, tend to appear in multi-year groups. To capture periodic changes in global climate, such as the Pacific decadal oscillation (PDO) or El Niño-Southern oscillation (ENSO) the frequency of storm appearance can change over time, while storms in a particular location can be treated as independent of one another.

We express the loss in period t as a fraction ${\delta_t}^C$ of the existing capital stock (the damage ratio) and assume that at least some of the damage in the previous period is made up for in the current period. The revised expression becomes

$$K_{t+1} = \underbrace{(1-\delta)K_t}_{\substack{\text{net existing}\\\text{stock}}} + \underbrace{I_t}_{\substack{\text{productive}\\\text{investment}}} - \underbrace{\delta_t^C K_t}_{\substack{\text{climate}\\\text{damage}}} + \underbrace{L_t}_{\substack{\text{loss \& damage}\\\text{expenditure}}} . \tag{6}$$

Equation (6) formulates climate damage as a depreciation rate shock. As noted in the introduction, we work in this paper within a structuralist tradition [5,16,17], in which economic actors face irreducible uncertainty about the future. In the Materials and Methods, we develop a climate damage model where economic actors anticipate future states of the world according to a stochastic wind speed model, but we allow for the possibility that they are mistaken. That is, actors are taken to assume a stochastic wind speed model, and we apply such a model in simulations, but the two models need not agree. Moreover, even when they do agree, it is possible to have an unusual sequence of devastating storms that exceed anticipated damage. In contrast, economic actors in neoclassical models make optimal decisions given probabilistic knowledge of future states of the world as they occur in the model. Real business cycle (RBC) models make a further "new classical" assumption that economic actors respond rapidly to the information available to them. Such models predict that depreciation rate shocks will have very little effect on economic output [45,46]. In "New Keynesian" models [47], where actors may not respond rapidly to new information, or an RBC model in which actors do not take climate shocks into account [19], depreciation rate shocks can produce an effect. In the model developed in this paper, when accurately anticipated, depreciation rate shocks from climate events can be accounted for in the design of physical capital, but as noted above, expected damage may differ from realized damage, either because of the particular sequence of storm events or because the climate is changing in ways that economic actors did not anticipate.

The investment I_t that appears in Equation (6) represents gross additions to productive capital stock. However, some capital expenditure is non-productive, including the cost of hardening capital to withstand a particular magnitude of climate event. We use x to denote the magnitude of an event, while x_d is the magnitude of the "design event". The engineer's task is to design the physical capital stock such that any event of magnitude less than x_d should inflict minimal damage, while allowing for some damage for events above that level. We assume that the total cost of capital, when built to withstand an event of magnitude x_d, inclusive of adaptation cost, is a multiple $m_a(x_d)$ of the cost of the productive capital. This and subsequent assumptions can be checked and refined using empirical engineering data. Denoting the total cost with I^{tot}, we write a modified Equation (6),

$$K_{t+1} = (1-\delta)K_t + \frac{1}{m_a(x_d)} I_t^{\text{tot}} - \delta_t^C K_t + L_t. \tag{7}$$

If no storms are provided for, so that $x_d = 0$, then there are no adaptation costs, and therefore $m_a(0) = 1$. The adaptation costs rise with the magnitude of the design event, so $m'_a > 0$. We assume declining marginal effectiveness of mitigation expenditure, which translates to rising marginal costs at higher design event magnitude, and therefore $m''_a > 0$ as well.

The final term in Equation (6) is the cost of rebuilding damaged capital (loss and damage). For the purposes of the present paper, we make a simple behavioral assumption, that damage is rebuilt, but at most a fraction ℓ of GDP can be devoted to rebuilding in any period. This means that there will ordinarily be a stock of damaged capital waiting to be rebuilt, D, where

$$D_{t+1} = D_t + \delta_t^C K_t - L_t. \tag{8}$$

With that assumption,

$$L_t = \min(\ell Y, D_t). \tag{9}$$

That is, the entire stock of damaged capital is repaired if funds permit. Otherwise, loss and damage expenditure is limited to the maximum available funds for repairs. This assumption makes loss and damage expenditure endogenous, controlled only by the expenditure fraction ℓ. It could be relaxed to allow for different responses, including the choice to migrate rather than rebuild. That is, indeed, a strategy pursued at the household level within US counties [22], but it is significantly more difficult to emigrate from a sovereign small island state than from a county within a large continental economy.

2. Materials and Methods

In this section we develop a model for climate damage to productive capital stocks. We first discuss the relevant calculations under a stationary climate, then under a non-stationary climate, and then construct a model specifically for Barbados.

2.1. Balancing Construction Costs against Climate Damage under Stationarity

For commercial infrastructure, such as we consider in this paper, an explicit cost-benefit calculation is often applied to investment in protective capital. We implement such a calculation in this section. In contrast, public infrastructure is usually built according to a specified return period (e.g., a 50-year event). In that case, the magnitude of the design event can be calculated from the design return period and the probability distribution $F_X(x)$ using Equation (2).

For commercial investment, we note that a given level of gross investment I^{tot} includes both the gross increment of productive capital I and adaptation costs. From Equation (7), the relationship is

$$I = \frac{1}{m_a(x_d)} I^{\text{tot}}. \tag{10}$$

To weigh adaptation cost against the reduction in future damage, we add to the construction cost the discounted potential damage to (depreciated) productive capital. In this case we need the average expected storm damage, which will depend on both the design event and the shape of the distribution. We write this as $\bar{\delta}^C(x_d; \boldsymbol{\sigma})$, where σ is a vector of parameters for the distribution. Assuming stationarity, and a discount rate i, the discounted average cost of repairing damage, C_d, is equal to

$$C_d = \frac{\bar{\delta}^C(x_d; \boldsymbol{\sigma}) I}{1+i} \sum_{t=0}^{\infty} \left(\frac{1-\delta}{1+i} \right)^t = \frac{\bar{\delta}^C(x_d; \boldsymbol{\sigma}) I}{\delta + i}. \tag{11}$$

In this equation, the discounted value of productive capital declines at the normal depreciation rate, excluding climate damage. We assume that climate damage is fully repaired in the subsequent period, so it adds to the cost with a one-period discount. (The simulation model described later in the paper has a quarterly time step.) This is a more restrictive assumption than in Equation (6), where expenditure on repairs can extend over several time periods. We adopt it both because it greatly simplifies the calculation and because it is meant to represent the calculation of an engineer attempting to find an optimal design threshold. From that vantage point, the engineer would have little basis to guess how long repairs might be delayed due to future cash-flow constraints. The result is an overestimate of the actual discounted repair costs, because the discount applies to the start of the rebuilding period, but it is not applied over the course of rebuilding.

The total cost C can now be expressed as

$$C = I^{\text{tot}} + \frac{1}{\delta + i}\overline{\delta}^{C}(x_d; \boldsymbol{\sigma})I = \left(m_a(x_d) + \frac{1}{\delta + i}\overline{\delta}^{C}(x_d; \boldsymbol{\sigma})\right)I. \tag{12}$$

This “engineering” cost contains only internal costs borne by the entity that must build and maintain the capital stock. It excludes actual or imputed external costs, and it does not consider social benefits. Thus, it seeks to represent the costs to which economic actors respond. Alternative assumptions, such as insuring new investment against climate damage, can be implemented by modifying this equation.

Good engineering practice suggests that the design should minimize the total engineering cost [48], which is achieved when x_d satisfies

$$m'_a(x_d) = -\frac{1}{\delta + i}\frac{\partial\overline{\delta}^{C}(x_d; \boldsymbol{\sigma})}{\partial x_d}. \tag{13}$$

This is a general expression that depends on the precise forms for the marginal adaptation cost and damage ratio. For the simulation model we assume specific functional forms, which we introduce below.

We emphasize that the calculation that results in Equation (13) is not a social welfare calculation, so it does not suffer from the problems raised by Pindyck [49] regarding IAMs. Rather, it represents a textbook present-worth analysis of equal-life alternatives for an engineering project (e.g., see [50]). The discount rate in Equation (11) is the one that a firm would choose when comparing between competing investments (a financial discount rate). We, therefore, avoid the contentious debate over the appropriate social discount rate [51]. Unlike social discount rates, for which experts provide a wide range of values [52], discount rates used by firms for investment decisions are comparatively standard and uncontroversial. The alternatives being compared in the present-worth calculation are represented by different design event magnitudes x_d. The “equal-life” condition is met through the assumption that any damage will be rebuilt. When the design magnitude satisfies Equation (13), present worth is maximized because the discounted costs are minimized.

2.2. Balancing Construction Costs against Climate Damage under Non-Stationarity

In a changing climate in which storms are expected to become more severe over time, the choice of design period is not straightforward. Designing for the current climate means under-designing, while designing for the expected climate at the end of the design life means over-designing. The minimum cost is achieved somewhere in between [41].

We capture non-stationarity by introducing a time-varying fractional damage cost function into Equation (11), the discounted cost of repairing damage,

$$C_d = \frac{I}{1+i}\sum_{t=0}^{\infty}\left(\frac{1-\delta}{1+i}\right)^{t}\overline{\delta}^{C}(x_d; \boldsymbol{\sigma}(t)). \tag{14}$$

This is a general expression. It depends on the marginal adaptation cost, the dependence of the damage ratio on the event magnitude, and changes in the parameters of the distribution of storm events. Below, we argue that the mean damage function can be assumed to grow exponentially over time,

$$\overline{\delta}^{C}(x_d; \boldsymbol{\sigma}(t)) \cong e^{at}\overline{\delta}^{C}(x_d; \boldsymbol{\sigma}(0)). \tag{15}$$

With this approximation we can explicitly compute the sum in Equation (14) to find

$$C_d = \frac{\overline{\delta}^C(x_d; \boldsymbol{\sigma}(0))I}{\delta + i - (1-\delta)(e^a - 1)}. \tag{16}$$

Following the same steps as before, we find that the magnitude of the design event should satisfy

$$m'_a(x_d) = -\frac{1}{\delta + i - (1-\delta)(e^a - 1)} \frac{\partial \overline{\delta}^C(x_d; \boldsymbol{\sigma}(0))}{\partial x_d}. \tag{17}$$

We return to this expression below, after first constructing a non-stationary statistical model for peak wind speed.

2.3. Wind Speed Model

A number of distributions are commonly used to describe the distribution of extremes in hydrology and meteorology [29]. We use the generalized extreme value (GEV) distribution, which encompasses three families of distribution. The extreme value (EV) type I distribution (also called the Gumbel) describes the distribution of the largest observation in samples arising from parent distributions with exponential tails (e.g. the normal and gamma distributions), and it corresponds to a GEV with zero shape parameter. The EV II distribution (also called the Fréchet), corresponding to positive GEV shape parameters, exhibits heavy or fat tails meaning that extreme quantiles can be quite large. The EV III distribution (also called the Weibull), corresponds to negative GEV shape parameters, is bounded by zero and is typically used to model the distribution of the smallest observation in a sample, for instance low-flows in an annual streamflow record. The cumulative density function of the GEV distribution is given by

$$P(x) = e^{-s(z(x),\xi)}, \quad z(x) = \frac{x-\mu}{\sigma}, \tag{18}$$

where

$$s(z,\xi) = \begin{cases} (1+\xi z)^{-1/\xi}, & \xi \neq 0, \\ e^{-z}, & \xi = 0. \end{cases} \tag{19}$$

while the probability density function is

$$p(x) = \frac{1}{\sigma} s(z(x),\xi)^{\xi+1} e^{-s(z(x),\xi)}. \tag{20}$$

In these expressions, x represents the magnitude of a particular event. The distribution has a location parameter μ and scale parameter, σ, each with the same units as x, and a dimensionless shape parameter ξ.

We now turn to the specific case of Barbados. Details of the wind speed model are provided in the Appendix A. We took data on storms from the Caribbean Hurricane Network's StormCARIB website (https://stormcarib.com), which included dates, peak wind speed, storm classification, and name for storms in the Caribbean. Data are available for Barbados specifically, as well as for the Eastern Caribbean as a whole, from the mid-19th Century through 2010. The StormCARIB data are based on "best track" data from the U.S. National Hurricane Center's North Atlantic hurricane database reanalysis project (HURDAT) [53].

The model suggested by the exploratory data analysis, where the probability that a certain peak wind speed will be exceeded in Barbados, is derived from a peak wind speed distribution for the Eastern Caribbean as a whole, which is modeled using a generalized extreme value (GEV) distribution. Therefore, we use the following model for Barbados,

$$P_{\text{BRB}}(w > w_t) = p_s P_{\text{EC}}(w > \phi w_t), \tag{21}$$

where, p_s is the strike probability, specifically, the probability that a storm in the Eastern Caribbean passes within 60 nautical miles, or 69 miles of the island. The parameter ϕ is the average value of the peak wind speed in the Eastern Caribbean divided by the peak wind speed observed in Barbados. As discussed in the Appendix, our estimate for p_s is 0.36 and for ϕ is 1.34. The probability distribution P_{EC} is a cumulative GEV distribution.

To simulate a non-stationary climate, the parameters for the GEV model parameters depend on the global average sea surface temperature (more precisely, the sea surface temperature anomaly relative to the 1961–1990 average). The motivation for this covariate is that tropical storm intensity tends to rise with sea surface temperature [54], although not uniformly, because temperature and pressure in the atmosphere also affect the intensity of storms [55]. Localized temperature extremes can also impact economic performance [18,56], but here our focus is on temperature averaged over large areas as a covariate with storm intensity.

The Appendix details our procedure for estimating the location, scale, and shape parameters for the Eastern Caribbean and gives their values. To obtain estimates for Barbados, we divided the location and scale parameters for the Eastern Caribbean by $\phi = 1.34$, leaving the shape parameter unchanged. Using the central estimates for the parameters, we find $\mu = 48.9 + 27.2\tau$ mph, $\sigma = 34.2$ mph, $\xi = -0.37$, where, τ is the global average sea surface temperature anomaly. The average anomaly between 1850 and 2010 was $\tau = -0.13$ °C, corresponding to $\mu = 45.4$ mph. Combined with the estimate of 0.36 for p_s, that gives the return periods (shown in Table 1) for Barbados for tropical storms and category 1–5 hurricanes according to the Saffir-Simpson scale. Table 1 also shows the observed frequencies from the StormCARIB database. The estimates are in reasonable agreement with observation, given the comparatively small number of observations for hurricanes.

Table 1. Estimated and observed return periods for storms classified on the Saffir–Simpson scale.

		Return Period (years)		
Category	**Threshold (mph)**	**GEV Estimate**	**Observed**	**Number of Observations**
Tropical storm	18	3	3	46
CAT 1	74	9	13	6
CAT 2	96	25	26	3
CAT 3	111	82	52	3
CAT 4	130	2594	NA	0
CAT 5	157	Infinite	NA	0

We note, that it is possible that the probability of Eastern Caribbean storms to strike Barbados, captured by the parameter p_s, may change in the future. Historically, most storms have missed Barbados, but if the hurricane belt migrates southward as the climate changes, then the frequency could increase.

2.4. Calculating Average Climate Damage

We expect the damage ratio $\delta^C(x; x_d)$ (the fraction of productive capital lost in an event that exceeds the design threshold) to rise with the magnitude of the event and fall with the threshold. Below the threshold the loss is zero, while at some magnitude above the threshold, damage will reach 100%. Damage models used in engineering depend on the type of hazard. For storms, structural damage depends on wind speed and the size of the storm [57] and, near the coast, storm surge [58]. Detailed studies consider the vulnerabilities of different structural components [59,60]. In the simplest models, the damage ratio rises as the wind speed to a power [61,62], as shown in Figure 1.

$$\bar{\delta}^C(x_d; \boldsymbol{\sigma}) = \int_{x_d}^{x_{\max}} dx\, p(x; \boldsymbol{\sigma})\delta^C(x; x_d). \tag{22}$$

The maximum event magnitude, $x_{\max}$, depends on the distribution. In the specific case of the distribution we use for storm events in Barbados, we write this equation using the rescaled location and scale parameters, as

$$\bar{\delta}^C(x_d;\boldsymbol{\sigma}) = p_s \int_{x_d}^{x_{\max}} \frac{dx}{\sigma} s(z(x),\xi)^{\xi+1} e^{-s(z(x),\xi)} \delta^C(x;x_d), \tag{23}$$

where, the vector of distributional parameters σ = (p_s, μ, σ, ξ). This equation gives a general expression for the mean damage ratio when extreme events follow the rescaled GEV distribution that we have estimated for Barbados. We next specify a functional form for the damage ratio.

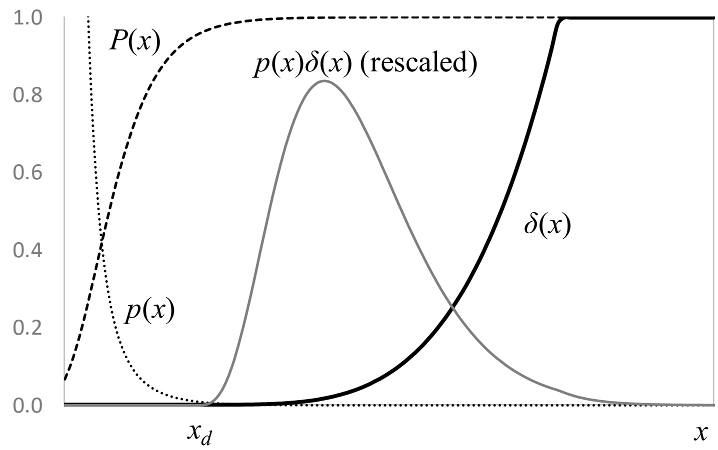


Figure 1. Hypothetical distribution and damage as functions of event magnitude. The average damage ratio $\bar{\delta}^C(x_d;\boldsymbol{\sigma})$ can be computed as.

Statistics for Barbados do not include casualty losses to commercial capital stocks. To find an estimate for the historical value for the average damage ratio, we took the estimate of GDP losses in Barbados due to storms from Acevedo [33]. For storms passing within 60 nautical miles, he found average annual losses of 0.2% of GDP. Not all of that will be associated with damage to productive capital. Assuming (somewhat arbitrarily) that half of the loss of GDP is due to loss of productive capital, we multiply 0.1% per year of GDP by the long-run average capital-output ratio of 4.2 years (estimated from data from the Penn World Table v. 9.1 [44]), to find an estimated capital loss of 0.42% per year.

Past studies have found that climate damage can be assumed to increase with wind speed to a power. Nordhaus [61], in a widely-cited study, found damage in the US to rise as the 9th power of the maximum wind speed, while Bouwer and Wouter Botzen [62] found damages to rise as the 8th power. Both estimates are well above conventional models based on physical processes that suggest a power of two or three. In a study that accounted for the size of the storm, as well as peak wind speed, Zhai and Jiang [57] found an exponent on wind speed of 5. In a US context, Murphy and Strobl [63] and Strobl [22] adopted values of 3 and 3.17. In a study of Latin American and the Caribbean, Strobl [20] estimated a value of 3.8, while for the Caribbean alone, Acevedo [33] found the power to be 3. We adopt the Acevedo's estimate as the power in our model, and apply it to wind speeds above the design threshold. Thus, we assume

$$\delta^C(x;x_d) = \frac{A}{x_{d0}^n}\max(0,x-x_d)^n, \quad n=3. \tag{24}$$

The parameter A is a scale factor to be found through calibration. To make A dimensionless, we divide it by the initial value of x_d, x_{d0}, to the power n. Substituting into Equation (23), we find an expression for the mean damage ratio. Computing the resulting integral numerically for $x_d = x_{d0} = 65$ mph and the estimates of μ, σ, and ξ reported earlier gives and setting the result equal to 0.42% per year (our estimate for the initial mean damage ratio) gives a value for A of 0.12.

We constructed a numerical estimate of the mean damage ratio using these parameters and a range of possible values for x_d and the sea-surface temperature anomaly τ. To a good approximation, we found that

$$\ln \bar{\delta}^C(x_d; \boldsymbol{\sigma}) \cong \ln p_s - 1.30 - 0.06x_d + 1.54\tau. \quad (25)$$

From this expression we can identify the parameter a in Equation (15) as 1.54 r_τ, where, r_τ is the rate of increase in sea surface temperature in °C per year. An automated search for breakpoints in a piecewise linear fit to the Hadley temperature anomaly series identified breakpoints in 1876, 1913, 1939, and 1973. From 1973 to the end of the series, the temperature has been rising at 0.013 °C per year, giving an estimate for a of 0.022/year. However, as we discuss below when describing the scenarios, it is likely to rise more rapidly in the future.

Next, we specify the form of the adaptation cost function. In principle, and in actual engineering practice, this can be calculated from cost data for structures that can withstand events of different magnitudes (for an example, see [64]). However, aggregate data are not readily available, so for this paper, we assume a one-parameter function. As discussed earlier, when taking the extreme case in which capital stocks are not hardened at all ($x_d = 0$), there are no adaptation costs and $m_a(0) = 1$. Under an assumption of decreasing returns to adaptation expenditure, we adopt an exponential cost function,

$$m_a(x_d) = e^{\theta x_d}. \quad (26)$$

Using Equation (13) and the approximate function in Equation (25),

$$\theta e^{\theta x_{d0}} = \frac{0.02\%}{\delta + i}. \quad (27)$$

Barbados' depreciation rate has been falling over time, and particularly sharply since 1982. From the Penn World Table v. 9.1 [44], the 1960–2017 average was 7.7% per year. Assuming a discount rate of 7.0% per year (a typical value for engineering projects), this gives an estimate for θ of 0.0015/mph.

Using these parameter values, and Equation (25) as an approximation for the average damage ratio, we computed x_d using (17), to find:

$$x_d = 40.4 + 17.2 \ln \frac{p_s^e}{\delta + i - (1-\delta)\left(e^{1.54 r_\tau^e} - 1\right)} + 26.5\, \tau^{\text{accept}}. \quad (28)$$

We added a superscript "e" on the strike probability p_s and the rate of increase in the sea surface temperature anomaly r_τ because they represent (possibly incorrect) expectations of future climate. The sea surface temperature anomaly at the time of construction has a subscript "accept" to capture the possibility that the accepted value may not reflect current conditions. We use this expression in the simulations.

2.5. Linking to a Macroeconomic Model

In this section we develop a model of capital accumulation for Barbados to illustrate the operation of the climate damage model. Three of the authors (EKB, CD, and TL) previously developed a macroeconomic model for Caribbean SIDS that includes export dependence and external debt [5]. In that model, capital accumulation is endogenous, depending on anticipated demand and capital utilization. It could be extended to respond to losses, as well; Miethe [65] has shown that financial activity in small islands declines after a hurricane, except for offshore financial centers (OFC). (The volume of international investment flowing to Barbados is not sufficiently large relative to its GDP for it to be classified as an OFC [66].) In this paper, we focus on climate impacts and anticipatory behavior, and specify capital accumulation exogenously leaving the combination of the models for future work.

Capital stocks with different design thresholds x_d are affected to different extents by climate damage. Therefore, we construct a vintage model, with vintages $v = 65, 66, \ldots, 150$, corresponding to ranges for the design thresholds x_d of (65, 66), (66, 67), ... , (149, 150) mph. The design threshold at a given time is selected using Equation (28) given expectations for future climate and observations of current conditions. Capital accumulation follows Equation (6) for each vintage,

$$K_{v,t+1} = (1-\delta)K_{v,t} + I_{v,t} - \delta^C_{v,t}K_{v,t} + L_{v,t}. \tag{29}$$

Climate damage is calculated using the actual, not anticipated, climate, while the vintage corresponding to the design threshold is determined based on the anticipated climate.

GDP, Y, is given by a capital productivity κ multiplied by the total capital stock,

$$Y_t = \kappa \sum_{v=65}^{125} K_{v,t}. \tag{30}$$

For the loss and damage calculation, we maintain a stock of damaged capital for each vintage, constrain total loss and damage expenditure to lie below a fixed share of GDP, ℓ (set to 20% in model runs) and allocate it to different vintages based on their representation in the pool. Specifically,

$$L_{v,t} = \frac{D_{v,t}}{\sum_{v'=65}^{125} D_{v',t}} \min\left(\ell Y, \sum_{v'=65}^{125} D_{v',t}\right). \tag{31}$$

We base our economic parameters on the Penn World Table v. 9.1 [44]. For the purposes of this paper we make simplifying assumptions in order to focus on climate damage.

First, we assume that investment grows at a steady rate g, which we anchor to the historical growth rate of the capital stock. Barbados' capital stock growth has been very slow since the Great Financial Crisis. Assuming a recovery to pre-crisis patterns, but not to the extraordinarily high growth rates of the 1960s and 1970s, we assume g to equal the 1980–2007 average rate of 2.7% per year. All investment at time t flows to the vintage corresponding to the design threshold at time t as calculated from Equation (28),

$$I_{d,t} = \begin{cases} I_o(1+g)^t, & x_d \in [v, v+1), \\ 0, & x_d \notin [v, v+1). \end{cases} \tag{32}$$

Second, we link capital stock to GDP using a constant capital productivity, and we assume a constant depreciation rate. Neither of these assumptions is strictly true (see Figure 2). However, for both parameters, a fit to the historical data is consistent with a gradual approach toward asymptotic values. Extrapolating those trends and taking the average over the scenario period (2017 to 2050) gives an average capital productivity of 0.17 per year and an average depreciation rate of 3.8% per year.

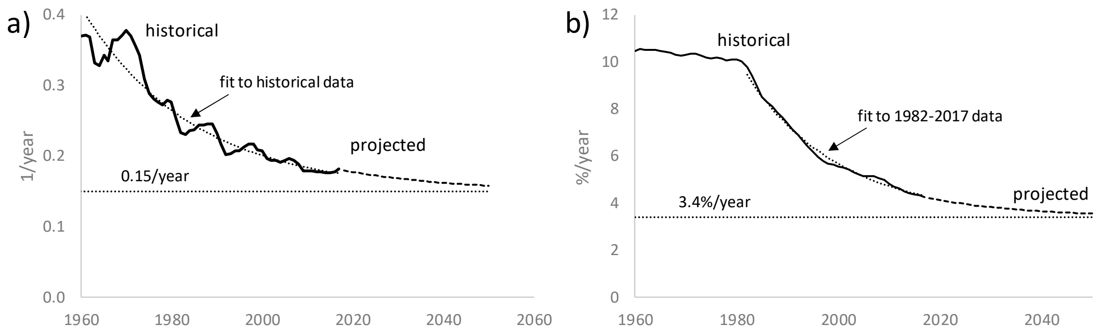


Figure 2. Capital productivity (**a**) and depreciation rate (**b**) for Barbados, historical and projected.

We initialize GDP to the 2017 value of Bds$9.35 billion (from the World Bank World Development Indicators database). Over the five-year period 2014–2018, the mean sea surface temperature anomaly was $\tau = 0.53$ °C, corresponding to $\mu = 63.5$ mph. We adopt that as the starting value.

3. Results

We built the model described above as a system dynamics model in Vensim. (Code is available from the authors upon request; the model requires Vensim DSS.) We ran three scenarios: stationary (a stationary climate); non-stationary no anticipation (non-stationary climate but a design threshold that does not anticipate any climate change); and non-stationary with anticipation (non-stationary climate with accurate anticipation of future climate). We note that a further (and arguably far more likely) scenario is a non-stationary climate in which climate change is anticipated, but inaccurately. However, the scenarios we have chosen are sufficient for the purpose of this paper, which is both to demonstrate the model and to explore whether anticipatory behavior (or lack of it) can substantially affect both adaptation costs and loss and damage.

Each scenario was run from 2017 to 2050 in Monte Carlo mode, with storm parameters drawn from a GEV distribution. For the temperature anomaly we used trends from MAGICC/SCENGEN 5.3 [67] (which reports global average temperature rather than sea surface temperature) with the "no policy" P50 scenario. We adopted a piecewise linear rate of increase with breaks in 2030 and 2040, from 0.53 °C in 2017, to 0.85 °C in 2030, 1.17 °C in 2040, and 1.52 °C in 2050. Because storms represent extreme events, it takes a very large number of runs to generate a representative distribution. However, a smaller number of runs is sufficient to give an idea of trends. We ran each scenario 10,000 times, using the same pseudo-random number sequence for each scenario. The results are shown in the figures below. In each figure, the bands correspond, under stationary conditions, to 5-year return events (80%), 20-year events (95%), 100-year events (99%), and 500-year events (99.8%). In addition, the outer boundary for all events (100%) is shown. The mean value is shown as a yellow line.

Figure 3 shows adaptation expenditure as a share of GDP in the three scenarios. In the stationary scenario, even at the 99.8% level, adaptation expenditure remains below 5% of GDP. It rises through anticipatory behavior in the non-stationary with anticipation scenario. In the non-stationary no anticipation scenario, delays in rebuilding lead to a fall in GDP in the more extreme scenarios, so although costs are the same as in the stationary case, they rise as a share of GDP.

Figure 4 shows loss and damage expenditure as a share of GDP in the three scenarios. Following the model assumptions, loss and damage expenditure in any given year is capped at 20% of GDP, so repairs may take several years to complete. (The backlog of damaged capital starts at zero, giving the discontinuity in the graph in the first years.) Under stationary conditions, mean loss and damage is around 3% of GDP, and in 80% of cases loss and damage expenditure is below 10% of GDP, but due to the accumulation of a backlog, there is a good chance that expenditure can be higher. In at least 1% of cases (that is, 100–99%), it reaches the maximum level. Note that total damage will be even higher than is shown in the graph because the model does not take into account the duration of the storm and only tracks damage to productive capital stocks. Damage to houses, crops, municipal buildings, public infrastructure, and so on is not accounted for.

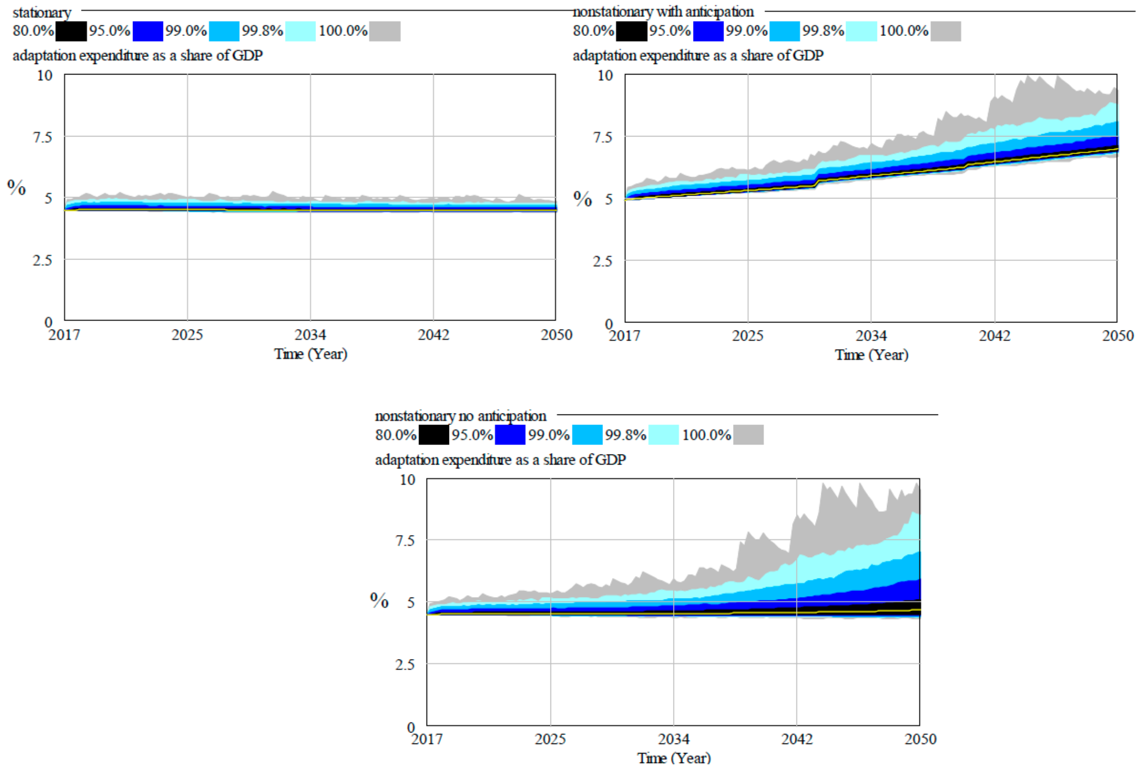


Figure 3. Adaptation expenditure as a share of GDP (as %) in the three scenarios.

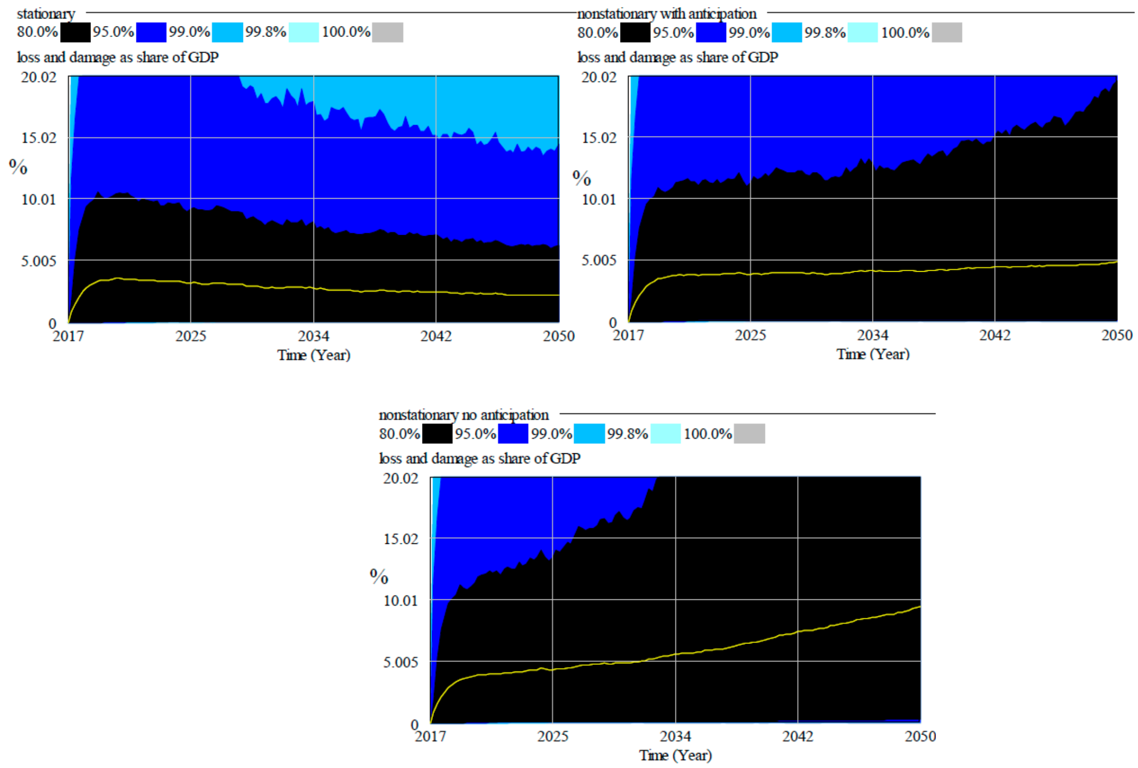


Figure 4. Loss and damage expenditure as a share of GDP (as %) in the three scenarios.

The difference between anticipation of climate change and building in line with historical climate change can be clearly seen in the non-stationary scenarios in Figure 4. The optimal design threshold trades off anticipated damage against mitigation cost, so damages rise in both non-stationary scenarios, with damage at the 95% (or 20-year) level overwhelming the capacity to rebuild in both scenarios. Yet, mean loss and damage expenditure rises only slightly in the non-stationary with anticipation scenario, while it rises substantially in the non-stationary no anticipation scenario.

IAMs report damage as a GDP loss. For purposes of comparison, we calculated the loss relative to a baseline in which GDP grows at a steady rate of 2.7% per year. The results are shown in Figure 5. The mean values are comparatively small in the stationary and non-stationary with anticipation scenarios (less than 1.0% of GDP) because damaged capital is rebuilt, and the investment expenditure is part of GDP. These values are higher than the 0.2% per year estimated by Acevedo [33] and the study of Moore et al. [6], which found output losses for Barbados between 0.20% and 0.25% of GDP in 2050. This is because the model tracks a backlog of unrepaired damaged capital stocks, and cumulative damage increases subsequent GDP losses (see the discussion in [19]). Without anticipation, mean losses are higher still, on the order of 4% by 2050. Moreover, due to cumulative damage and the rebuilding backlog, even with anticipation there is a significant probability of greater losses, as shown by the rise in the 80% and 95% confidence intervals.

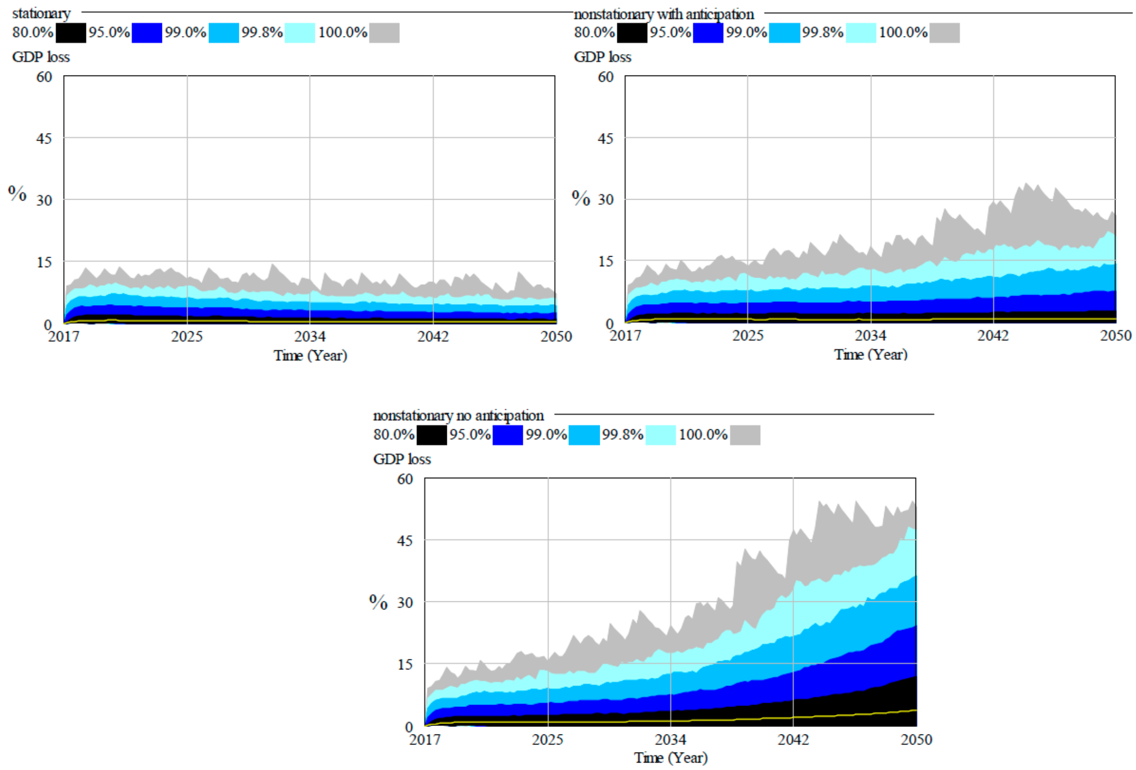


Figure 5. Output losses (as %) relative to a steady growth path in the three scenarios.

Consumption expenditures, and, therefore, living standards, are reduced because of expenditure for mitigation and loss & damage as well as from lower output due to damaged capital stocks. This is shown in Figure 6. In a stationary climate, even the most severe storms reduce consumption by no more than 0.5 percentage points of GDP. In a non-stationary climate, consumption losses can be substantial even when climate change is anticipated. We emphasize again that while our model includes forward-looking actors, they are not the social planners of the IAMs. Rather, they are engineers who attempt a minimum-cost design given their expectations of climate change at the time of construction. IAMs seek to maximize social welfare, which is normally taken to be an increasing function of household consumption. Thus, an IAM might produce a scenario with lower consumption losses and higher adaptation costs compared to the non-stationary with anticipation scenario that we present in this paper.

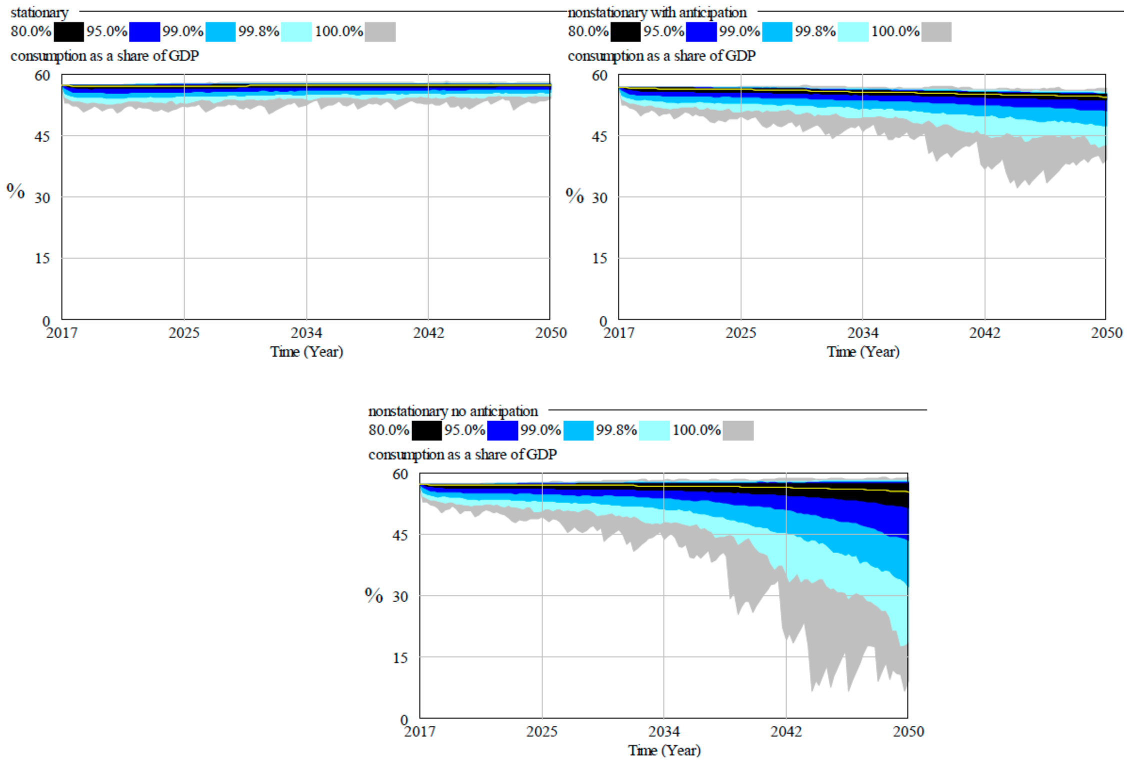


Figure 6. Consumption (as % of GDP) in the three scenarios.

4. Discussion

We drew on standard methods in engineering risk assessment to develop a model for damage to commercial productive capital in the small island state of Barbados. Detailed impact models like ours are often used for local studies; such studies inform the damage functions used in the FUND model [9]. However, to our knowledge there is no bottom-up macroeconomic model that includes damage to productive capital. The closest we have found are the papers of Fankhauser and Tol [26], which introduced a temperature-dependent depreciation rate into different types of neoclassical growth models; and of Rezai et al. [10], which applied a greenhouse gas concentration-dependent depreciation rate in a post-Keynesian model.

The behaviorally-based damage model presented in this paper allows for greater flexibility than do temperature-dependent damage functions. Anticipating a changing climate or designing for current conditions produce different effective depreciation rates for the same change in global temperature, in contrast to Fankhauser and Tol [26], Moore et al. [6], or Rezai et al. [10]. Firms may rebuild damaged capital (as assumed in this paper) or suffer an extended loss of output. They may target a particular rate of growth, while damage costs are made up through lower consumption (as in this paper and FUND) or damages may be reflected in lower output and correspondingly lower saving and investment (as in DICE and Fankhauser and Tol [26]).

The simulation results presented in this paper provide a counterpoint to the climate damage models used in integrated assessment models. When running IAMs in an optimizing mode, the results are highly dependent on an assumed social discount rate [68–73]. The analysis in IAMs is normative: the investment trajectory maximizes social utility, taken to be an increasing function of consumption. In contrast, in this paper the analysis is descriptive. The discount rate is one that might be used by a private firm deciding between different investments. The simulation results produced by the model can be reviewed and critically assessed, and policy instruments chosen to make a socially desirable outcome more likely. For example, we assumed that capital of a given vintage would be rebuilt to its original specifications. Instead, it could be built to specifications of new investment, thus following the recommendation to "build back better" [74]. Alternatively, sufficiently extensive damage could lead to abandonment and migration [75]. Additional behavioral extensions could include insurance against climate damage and publicly-funded recovery efforts in the calculation of total costs in Equation (12).

A further contrast is between the use of specific moments of distributions (such as the mean) and a full distribution, as shown above in the model outputs. The importance of looking at the full distribution in climate damage studies was urged by Weitzman [69,76]. IAMs, when run in an optimizing mode, assume that agents choose an optimal expected future path over which expectations are calculated as the mean across different possible future states. The results in this paper make clear how misleading mean values can be when distributions are asymmetrical and have broad tails. In Figure 5, when climate damage is anticipated, mean GDP losses rise only slightly over the current value. However, losses at the 95% level (corresponding in the stationary case to a 20-year event) roughly double by 2050, suggesting a substantial probability of hardship arising from storm damage.

5. Conclusions

The dominant approach to computing climate damages in economic models is to use a temperature-dependent damage function. This has some advantages at global level, where damage estimates are aggregates over highly heterogeneous local impacts. However, they are less appropriate for local studies, where a wide variety of modelled climate variables may be available, such as the frequencies of extreme climate events, and it is possible and relevant to explore alternative behavioral assumptions.

Local studies are particularly needed for small island developing states (SIDS), which must contend with the compound uncertainties of heavy reliance on export markets and potentially rising climate damage. SIDS rely on capital-intensive export industries, and both the capital stocks and transport costs can be affected by tropical cyclones.

In this paper we drew upon the literature on engineering design and risk assessment to develop a model for damage to commercial productive capital and applied it to the small island state of Barbados. The model features behavioral variables that are not captured by temperature-dependent damage functions, such as anticipation of future climate change. We found that anticipatory behavior can substantially affect climate impacts on the economy.

Author Contributions: Conceptualization, E.K.-B. and J.L.; formal analysis, E.K.-B., J.L., and T.L.; funding acquisition, E.K.-B.; investigation, E.K.-B. and C.D.; methodology, E.K.-B. and J.L.; project administration, E.K.-B.; writing—original draft, E.K.-B., J.L., T.L., and C.D.; writing—review and editing, E.K.-B., J.L., T.L., and C.D.

Funding: The work presented in this paper was funded in part by the Stockholm Environment Institute from funds provided by the Swedish International Development Cooperation Agency (Sida). It substantially extends earlier work carried out under the Global to Local Caribbean Climate Change Adaptation and Mitigation Scenarios (GoLoCarSce) and the Sustainable Water Management under Climate Change in Small Island States of the Caribbean (Water-aCCIS) research projects. GoLoCarSce was funded by the European Union African, Caribbean and Pacific (ACP) Research Programme for Sustainable Development (CP-RSD, Contract Number FED/2011/281-134). The funding for Water-aCCIS was provided by the International Development Research Centre (IDRC, Grant 107096-001). The results can under no circumstances be regarded as reflecting the position of Sida, the European Union, or IDRC.

Acknowledgments: The authors would like to thank John Agard and Adrian Cashman for their guidance on the GoLoCarSce and Water-aCCIS projects, which provided the foundation for the work presented here, and for their encouragement to build on that foundation in the writing of this paper.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A. Estimating Parameters for the Wind Speed Model

Data on storms for the Eastern Caribbean extends from 1851 to 2010, while that for Barbados extends from 1855 to 2010. We note that a bias in historical data identified by Landsea [77] appears to have been corrected in the HURDAT database [78]. Thus, in contrast to Acevedo [33], we do not adjust historical wind speeds. For three out of 58 storms that reached Barbados, the peak wind speed recorded in Barbados exceeded that recorded for the Eastern Caribbean. Since Barbados is part of the Eastern Caribbean, we considered those to be recording errors and set the ratios equal to one. Otherwise, we used the ratio of the recorded peak wind speed in the Eastern Caribbean to that in Barbados. The average ratio, which is our parameter ϕ, we found to be 1.34, with a standard deviation of 0.41. This parameter is comparatively stable over time, despite an apparent rising trend. A one-sided, two-sample, Wilcoxon rank sum test for whether the mean before 1931 (the median year for storms in Barbados) is lower than after 1931 could not reject the null hypothesis of no difference between the means ($p = 0.41$).

We used count data of storms per year to estimate a Poisson model for storms with a peak wind speed of at least 40 mph (using the R fitdistrplus package ver. 1.0-11) for both the Eastern Caribbean and Barbados. Graphical representations of the fit for the Eastern Caribbean are shown in Figure A1 and for Barbados in Figure A2. The parameter estimate for the Eastern Caribbean is $\lambda = 1.56 \pm 0.20$ (to two standard deviations), corresponding to a return period of 1.24 years, and for Barbados $\lambda = 0.37 \pm 0.10$, corresponding to a return period of 3.22 years. To estimate the strike probability in Equation (21), we computed a Poission fit for the Eastern Caribbean for storms with wind speed $w_t = \phi \times 40.0$ mph = 53.6 mph and compared the exceedance probability to that of a 40-mph storm in Barbados. The result is $p_s = 0.36$.

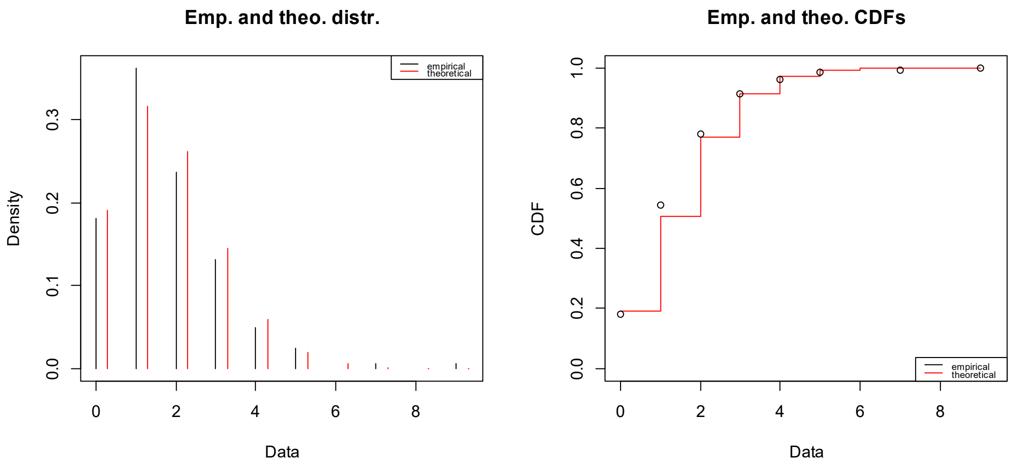


Figure A1. Poisson distribution fit for storm events in the Eastern Caribbean.

Next, we selected the peak wind speed in each year for the Eastern Caribbean. Wind speeds are not recorded for years without storms. Thus, there is no data for years when peak wind speed data fell below 40 mph, the minimum for a tropical storm. In those years we set the peak wind speed to a common value—the mean below the threshold—and fit a stationary GEV distribution (using the R package ismev ver. 1.42) that is truncated to the left at $x = 0$. We found the mean value below the threshold in an iterative procedure in which we: initialized the mean below threshold to one-half the threshold, fit the GEV, calculated the mean below the threshold with the fitted parameters, used that value for the next iteration, and iterated until the estimated mean below threshold converged to a tolerance of 10^{-7} mph. This procedure found an estimated mean (non-storm) peak wind speed below threshold of 3.74 mph.

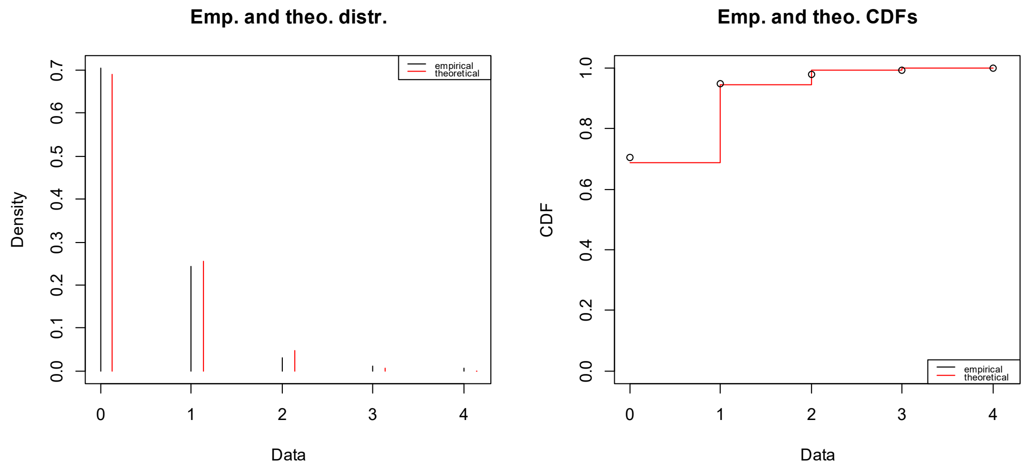


Figure A2. Poisson distribution fit for storm events in Barbados.

Diagnostic plots for the fitted GEV distribution are shown in Figure A3. As shown in the figure, the full GEV parameter set is needed to capture the behavior at high wind speeds (i.e., a Gumbel distribution would be inappropriate). The estimated parameters for the Eastern Caribbean are $\mu_{EC} = 60.1 \pm 8.1$ mph, $\sigma_{EC} = 46.0 \pm 5.9$ mph, $\xi_{EC} = -0.34 \pm 0.11$ (again to two standard deviations). This corresponds to a return period of 1.29 years for storms with the threshold peak wind speed (40 mph), in reasonable agreement with the Poisson estimate of 1.24 years.

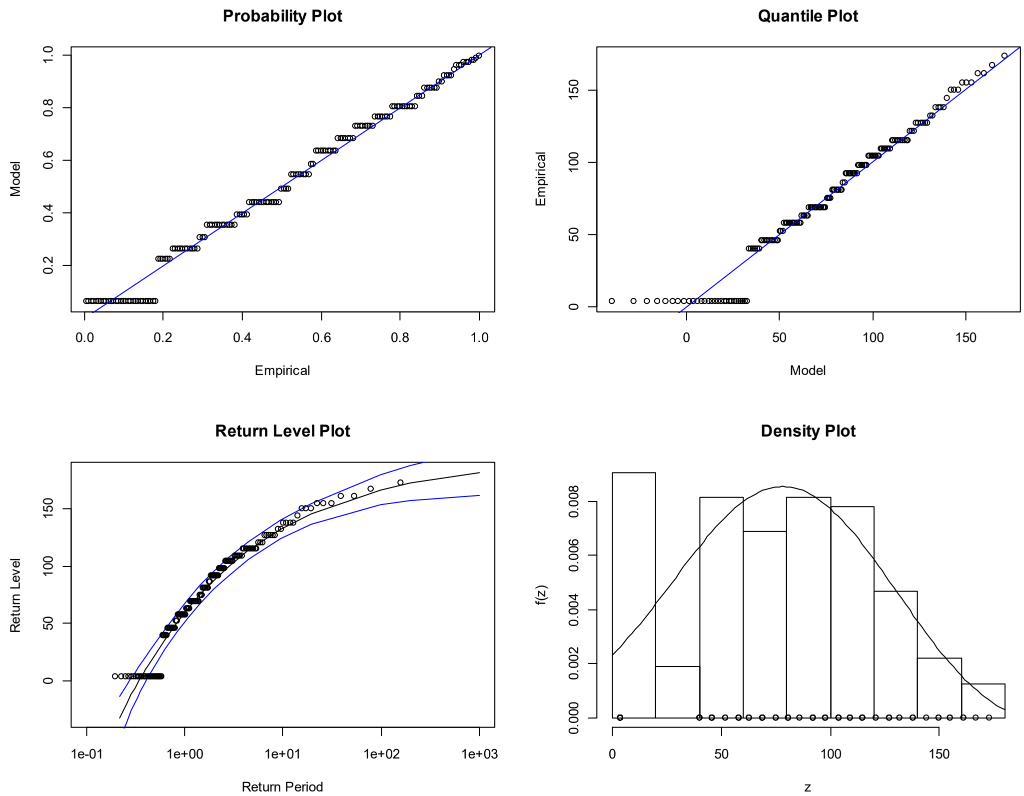


Figure A3. Diagnostic plots for storm data in the Eastern Caribbean as a stationary generalized extreme value (GEV).

For the non-stationary GEV model we used as a covariate the global average sea surface temperature anomaly, τ, relative to the 1961–1990 average from the Hadley Climate Research Unit (https://www.metoffice.gov.uk/hadobs/). The justification is provided in the main text. Sea surface temperature does not drive non-storm peak wind speeds, so we expect peak wind speeds in the upper part of the distribution to be more sensitive to sea surface temperature than in the lower part. Consistent with this assumption, Elsner et al. [79] found the upper quintiles of peak tropical storm wind speed to rise over time and with changing sea surface temperature, but not the lower quintiles. Accordingly, for this fit we again set the peak wind speed for years with no data to 3.74 mph, the value that we estimated for the stationary distribution.

Only the location parameter had a statistically significant correlation to sea surface temperature at the 5% level. Setting up a model with a temperature-dependent location parameter, the residual probability and quantile plots are shown in Figure A4. The estimated parameters are μ_{EC} = (65.6 + 36.7 τ) ± (9.1 + 29.7 τ) mph, σ_{EC} = 45.9 ± 6.1 mph, ξ_{EC} = −0.37 ± 0.12.

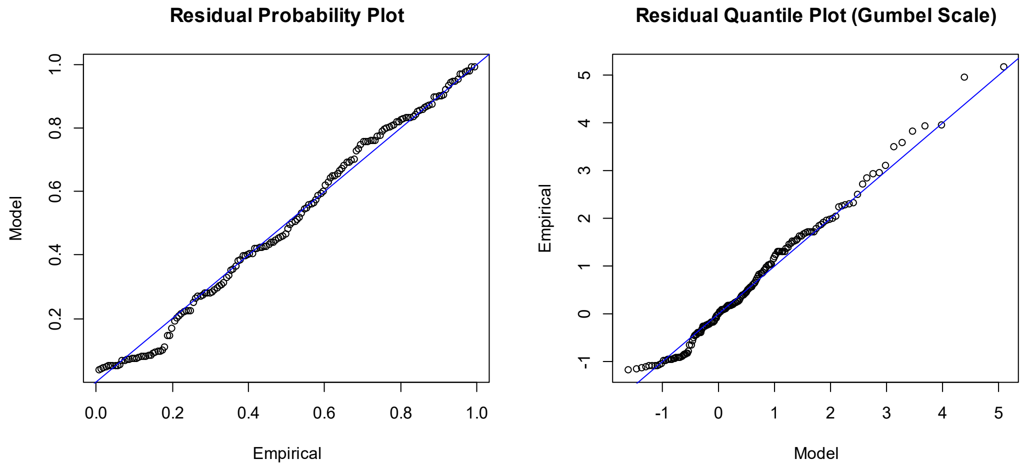


Figure A4. Diagnostic plots for the non-stationary GEV distribution.

References

1. Nicholls, R.J.; Tol, R.S.J. Impacts and responses to sea-level rise: A global analysis of the SRES scenarios over the twenty-first century. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **2006**, *364*, 1073–1095. [CrossRef] [PubMed]
2. Nurse, L.A.; McLean, R.F.; Agard, J.; Briguglio, L.P.; Duvat-Magnan, V.; Pelesikoti, N.; Tompkins, E.; Webb, A. Small islands. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change*; Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 1613–1654.
3. William, E.; Kraay, A. *Small States, Small Problems? SSRN Scholarly Paper ID 620631*; Social Science Research Network: Rochester, NY, USA, 1999.
4. Armstrong, H.W.; Read, R. The phantom of liberty? Economic growth and the vulnerability of small states. *J. Int. Dev.* **2002**, *14*, 435–458. [CrossRef]
5. Kemp-Benedict, E.; Drakes, C.; Laing, T. Export-led growth, global integration, and the external balance of small island developing states. *Economies* **2018**, *6*, 35. [CrossRef]
6. Moore, W.; Elliott, W.; Lorde, T. Climate change, Atlantic storm activity and the regional socio-economic impacts on the Caribbean. *Environ. Dev. Sustain.* **2016**, *19*, 707–726. [CrossRef]
7. Nordhaus, W.D. Rolling the 'DICE': An optimal transition path for controlling greenhouse gases. *Resour. Energy Econ.* **1993**, *15*, 27–50. [CrossRef]
8. Nordhaus, W.D. Revisiting the social cost of carbon. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 1518–1523. [CrossRef] [PubMed]
9. Anthoff, D.; Tol, R.S.J. *The Climate Framework for Uncertainty, Negotiation and Distribution (FUND): Technical Description, Version 3.6*; Forschungsstelle für Nachhaltige Entwicklung, Universität Hamburg: Hamburg, Germany, 2012.

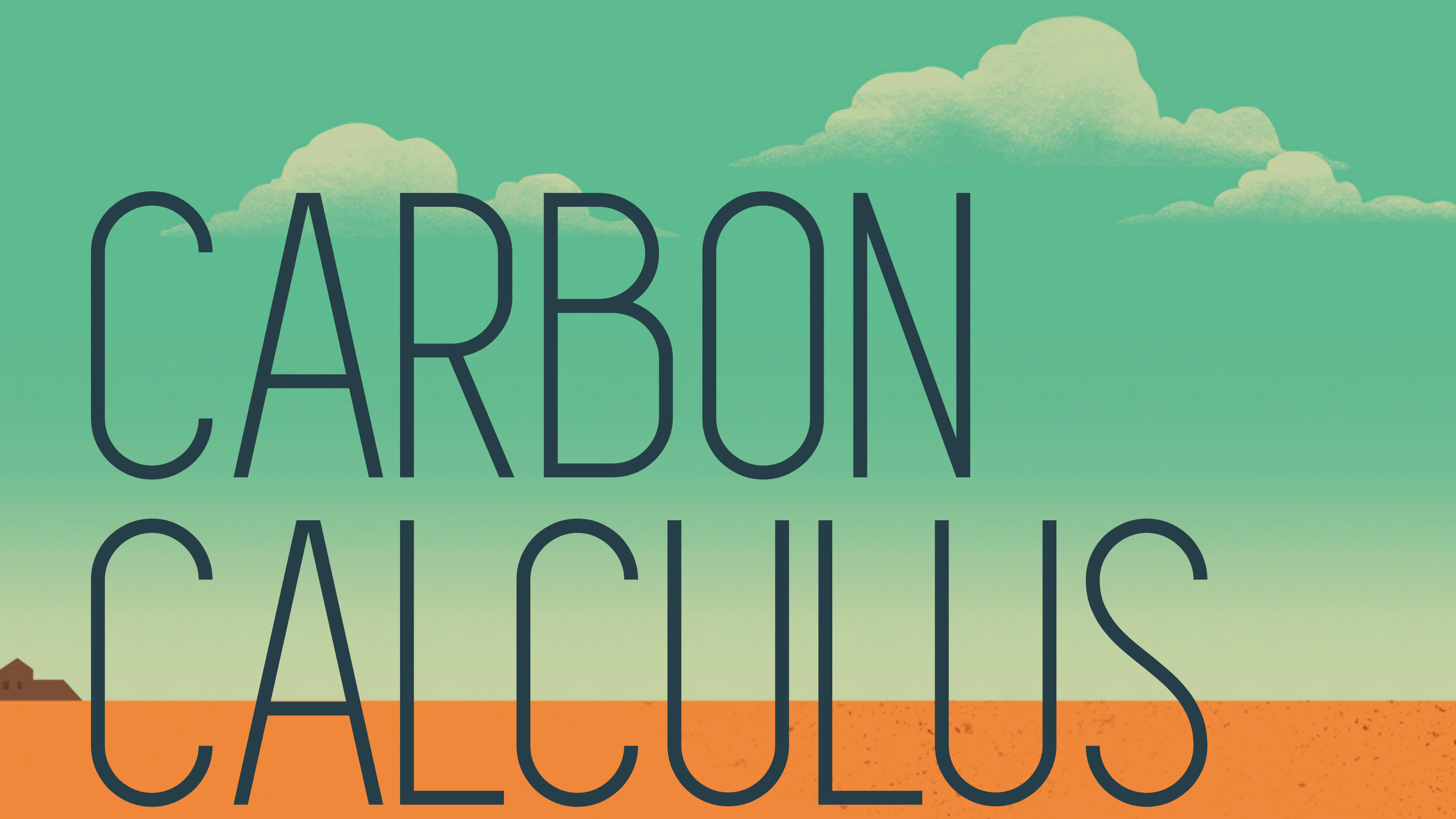
10. Rezai, A.; Taylor, L.; Foley, D. Economic growth, income distribution, and climate change. *Ecol. Econ.* **2018**, *146*, 164–172. [CrossRef]
11. Edmonds, J.A.; Wise, M.A.; MacCracken, C.N. *Advanced Energy Technologies and Climate Change: An Analysis Using the Global Change Assessment Model (GCAM)*; PNL-9798; Pacific Northwest National Lab. (PNNL): Richland, WA, USA, 1994.
12. Kim, S.H.; Edmonds, J.; Lurz, J.; Smith, S.J.; Wise, M. The objects framework for integrated assessment: Hybrid modeling of transportation. *Energy J.* **2006**, *27*, 63–91. [CrossRef]
13. Bréchet, T.; Camacho, C.; Veliov, V.M. Adaptive model-predictive climate policies in a multicountry setting. In *The Oxford Handbook of the Macroeconomics of Climate Change*; Bernard, L., Semmler, W., Eds.; Oxford University Press: Oxford, UK, 2015; pp. 114–138.
14. Tol, R.S.J. Estimates of the damage costs of climate change. Part I: Benchmark estimates. *Environ. Resour. Econ.* **2002**, *21*, 47–73. [CrossRef]
15. Tol, R.S.J. Estimates of the damage costs of climate change. Part II. Dynamic estimates. *Environ. Resour. Econ.* **2002**, *21*, 135–160. [CrossRef]
16. Taylor, L. *Reconstructing Macroeconomics: Structuralist Proposals and Critiques of the Mainstream*; Harvard University Press: Cambridge, MA, USA, 2004.
17. Ocampo, J.A.; Rada, C.; Taylor, L. *Growth and Policy in Developing Countries: A Structuralist Approach*; Columbia University Press: New York, NY, USA, 2009.
18. Donadelli, M.; Jüppner, M.; Riedel, M.; Schlag, C. Temperature shocks and welfare costs. *J. Econ. Dyn. Control* **2017**, *82*, 331–355. [CrossRef]
19. Piontek, F.; Kalkuhl, M.; Kriegler, E.; Schultes, A.; Leimbach, M.; Edenhofer, O.; Bauer, N. Economic growth effects of alternative climate change impact channels in economic modeling. *Env. Resour. Econ.* **2018**. [CrossRef]
20. Strobl, E. The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the Central American and Caribbean regions. *J. Dev. Econ.* **2012**, *97*, 130–141. [CrossRef]
21. Hallegatte, S.; Rozenberg, J. Climate change through a poverty lens. *Nat. Clim. Chang.* **2017**, *7*, 250–256. [CrossRef]
22. Strobl, E. The economic growth impact of hurricanes: Evidence from U.S. coastal counties. *Rev. Econ. Stat.* **2011**, *93*, 575–589. [CrossRef]
23. Noy, I. The macroeconomic consequences of disasters. *J. Dev. Econ.* **2009**, *88*, 221–231. [CrossRef]
24. IPCC. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*; Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., et al., Eds.; No. A Special Report of the Intergovernmental Panel on Climate Change Working Groups I and II; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2012.
25. USGCRP. *Fourth National Climate Assessment, Volume II: Impacts, Risks, and Adaptation in the United States*; Reidmiller, D.R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Lewis, K.L.M., Maycock, T.K., Stewart, B.C., Eds.; U.S. Global Change Research Program: Washington, DC, USA, 2018.
26. Fankhauser, S.; Tol, R.S.J. On climate change and economic growth. *Resour. Energy Econ.* **2005**, *27*, 1–17. [CrossRef]
27. Hirabayashi, Y.; Mahendran, R.; Koirala, S.; Konoshima, L.; Yamazaki, D.; Watanabe, S.; Kim, H.; Kanae, S. Global flood risk under climate change. *Nat. Clim. Chang.* **2013**, *3*, 816–821. [CrossRef]
28. Lin, N.; Kopp, R.E.; Horton, B.P.; Donnelly, J.P. Hurricane Sandy's flood frequency increasing from year 1800 to 2100. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 12071–12075. [CrossRef]
29. Stedinger, J.R.; Vogel, R.M.; Foufoula-Georgiou, E. Frequency analysis of extreme events. In *Handbook of Hydrology*; Maidment, D.R., Ed.; McGraw-Hill: New York, NY, USA, 1993.
30. Vogel, R.M.; Castellarin, A. Risk, reliability, and return periods and hydrologic design. In *Handbook of Applied Hydrology*; Singh, V.P., Ed.; McGraw-Hill Book Company: New York, NY, USA, 2017.
31. Organization of American States. *Primer on Natural Hazard Management in Integrated Regional Development Planning*; Organization of American States: Washington, DC, USA, 1991.
32. Economic Commission for Latin America and the Caribbean. *An Assessment of the Economic and Social Impacts of Climate Change on the Health Sector in the Caribbean*; Economic Commission for Latin America and the Caribbean, United Nations: Port of Spain, Trinidad and Tobago, 2011.

33. Acevedo, S. *Gone with the Wind: Estimating Hurricane and Climate Change Costs in the Caribbean*; IMF Working Papers; IMF: Washington, DC, USA, 2016; Volume 16, p. 1.
34. Sheehan, M. Hurricanes Harvey, Irma, and Maria Cost Re/Insurers $80bn: Impact Forecasting. *Reinsurance News*, 5 April 2018.
35. Ötker, I.; Srinivasan, S. Bracing for the storm. For the Caribbean building resilience is a matter of survival. *Financ. Dev.* **2018**, *55*, 1.
36. Langbein, W.B. Annual floods and the partial-duration flood series. *Eos Trans. Am. Geophys. Union* **1949**, *30*, 879–881. [CrossRef]
37. Rogger, M.; Agnoletti, M.; Alaoui, A.; Bathurst, J.C.; Bodner, G.; Borga, M.; Chaplot, V.; Gallart, F.; Glatzel, G.; Hall, J.; et al. Land use change impacts on floods at the catchment scale: Challenges and opportunities for future research. *Water Resour. Res.* **2017**, *53*, 5209–5219. [CrossRef] [PubMed]
38. Milly, P.C.D.; Betancourt, J.; Falkenmark, M.; Hirsch, R.M.; Kundzewicz, Z.W.; Lettenmaier, D.P.; Stouffer, R.J. Stationarity is dead: Whither water management? *Science* **2008**, *319*, 573–574. [CrossRef] [PubMed]
39. Serinaldi, F.; Kilsby, C.G. Stationarity is undead: Uncertainty dominates the distribution of extremes. *Adv. Water Resour.* **2015**, *77*, 17–36. [CrossRef]
40. Salas, J.D.; Obeysekera, J. Revisiting the concepts of return period and risk for nonstationary hydrologic extreme events. *J. Hydrol. Eng.* **2014**, *19*, 554–568. [CrossRef]
41. Read, L.K.; Vogel, R.M. Reliability, return periods, and risk under nonstationarity. *Water Resour. Res.* **2015**, *51*, 6381–6398. [CrossRef]
42. Vogel, R.M.; Yaindl, C.; Walter, M. Nonstationarity: Flood magnification and recurrence reduction factors in the United States. *JAWRA J. Am. Water Resour. Assoc.* **2011**, *47*, 464–474. [CrossRef]
43. McKenzie, R.; Levendis, J. Flood hazards and urban housing markets: The effects of Katrina on New Orleans. *J. Real Estate Financ. Econ.* **2010**, *40*, 62–76. [CrossRef]
44. Feenstra, R.C.; Inklaar, R.; Timmer, M.P. The next generation of the Penn World Table. *Am. Econ. Rev.* **2015**, *105*, 3150–3182. [CrossRef]
45. Ambler, S.; Paquet, A. Stochastic depreciation and the business cycle. *Int. Econ. Rev.* **1994**, *35*, 101–116. [CrossRef]
46. Dueker, M.; Fischer, A.; Dittmar, R. Stochastic capital depreciation and the co-movement of hours and productivity. *B.E. J. Macroecon.* **2007**, 6. [CrossRef]
47. Furlanetto, F.; Seneca, M. New perspectives on depreciation shocks as a source of business cycle fluctuations. *Macroecon. Dyn.* **2014**, *18*, 1209–1233. [CrossRef]
48. Fankhauser, S.; Smith, J.B.; Tol, R.S.J. Weathering climate change: Some simple rules to guide adaptation decisions. *Ecol. Econ.* **1999**, *30*, 67–78. [CrossRef]
49. Pindyck, R.S. Climate change policy: What do the models tell us? *J. Econ. Lit.* **2013**, *51*, 860–872. [CrossRef]
50. Blank, L.; Tarquin, A. *Engineering Economy*, 8th ed.; McGraw-Hill Education: New York, NY, USA, 2018.
51. Baum, S.D. Description, prescription and the choice of discount rates. *Ecol. Econ.* **2009**, *69*, 197–205. [CrossRef]
52. Weitzman, M.L. Gamma discounting. *Am. Econ. Rev.* **2001**, *91*, 260–271. [CrossRef]
53. Landsea, C.W.; Franklin, J.L. Atlantic hurricane database uncertainty and presentation of a new database format. *Mon. Weather Rev.* **2013**, *141*, 3576–3592. [CrossRef]
54. Holland, G.J. The maximum potential intensity of tropical cyclones. *J. Atmos. Sci.* **1997**, *54*, 2519–2541. [CrossRef]
55. Vecchi, G.A.; Soden, B.J. Effect of remote sea surface temperature change on tropical cyclone potential intensity. *Nature* **2007**, *450*, 1066–1070. [CrossRef]
56. Donadelli, M.; Jüppner, M.; Paradiso, A.; Schlag, C. Temperature volatility risk. *Ssrn Electron. J.* **2019**. [CrossRef]
57. Zhai, A.R.; Jiang, J.H. Dependence of US hurricane economic loss on maximum wind speed and storm size. *Environ. Res. Lett.* **2014**, *9*, 064019. [CrossRef]
58. Lin, N.; Emanuel, K.; Oppenheimer, M.; Vanmarcke, E. Physically based assessment of hurricane surge threat under climate change. *Nat. Clim. Chang.* **2012**, *2*, 462–467. [CrossRef]
59. Unanwa, C.O.; McDonald, J.R.; Mehta, K.C.; Smith, D.A. The development of wind damage bands for buildings. *J. Wind Eng. Ind. Aerodyn.* **2000**, *84*, 119–149. [CrossRef]

60. Vickery, P.J.; Skerlj, P.F.; Lin, J.; Twisdale, L.A.; Young, M.A.; Lavelle, F.M. HAZUS-MH hurricane model methodology. II: Damage and loss estimation. *Nat. Hazards Rev.* **2006**, *7*, 94–103. [CrossRef]
61. Nordhaus, W.D. The economics of hurricanes and implications of global warming. *Clim. Chang. Econ.* **2010**, *1*, 1–20. [CrossRef]
62. Bouwer, L.M.; Botzen, W.W.J. How sensitive are US hurricane damages to climate? Comment on a paper by W. D. Nordhaus. *Clim. Chang. Econ.* **2011**, *2*, 1–7. [CrossRef]
63. Murphy, A.; Strobl, E. *The Impact of Hurricanes on Housing Prices: Evidence from U.S. Coastal Cities*; Federal Reserve Bank of Dallas, Working Papers; Federal Reserve Bank of Dallas: Dallas, TX, USA, 2010.
64. USACE. *Risk Assessment for Flood Risk Management Studies*; Engineering Regulation USACE ER 1105-2-101; US Army Corps of Engineers: Washington, DC, USA, 2017.
65. Miethe, J. *Using Hurricanes to Uncover (Non-)Activity in Offshore Financial Centers*; Job Market Paper; Humboldt University Berlin and German Institute of Economic Research (DIW Berlin): Berlin, Germany, 2019.
66. Garcia-Bernardo, J.; Fichtner, J.; Takes, F.W.; Heemskerk, E.M. Uncovering offshore financial centers: Conduits and sinks in the global corporate ownership network. *Sci. Rep.* **2017**, *7*, 6246. [CrossRef]
67. Fordham, D.A.; Wigley, T.M.L.; Watts, M.J.; Brook, B.W. Strengthening forecasts of climate change impacts with multi-model ensemble averaged projections using MAGICC/SCENGEN 5.3. *Ecography* **2012**, *35*, 4–8. [CrossRef]
68. Tol, R.S.J. The marginal damage costs of carbon dioxide emissions: An assessment of the uncertainties. *Energy Policy* **2005**, *33*, 2064–2074. [CrossRef]
69. Weitzman, M.L. On modeling and interpreting the economics of catastrophic climate change. *Rev. Econ. Stat.* **2009**, *91*, 1–19. [CrossRef]
70. Ackerman, F.S.J.; DeCanio, R.B.H.; Sheeran, K. Limitations of integrated assessment models of climate change. *Clim. Chang.* **2009**, *95*, 297–315. [CrossRef]
71. Kopp, R.E.; Golub, A.; Keohane, N.O.; Onda, C. The influence of the specification of climate change damages on the social cost of carbon. *Econ. Open Access Open Assess. E-J.* **2012**, *6*, 2012–2013. [CrossRef]
72. Botzen, W.J.W.; van den Bergh, J.C.J.M. How sensitive is Nordhaus to Weitzman? Climate policy in DICE with an alternative damage function. *Econ. Lett.* **2012**, *117*, 372–374. [CrossRef]
73. IPCC. Summary for policymakers. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastandrea, M.D., Bilir, T.E., Chatterjee, M., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 1–32.
74. Hallegatte, S.; Rentschler, J.; Walsh, B. *2018. Building Back Better: Achieving Resilience through Stronger, Faster, and More Inclusive Post-Disaster Reconstruction. Risk and Vulnerability Assessment*; World Bank: Washington, DC, USA, 2018.
75. Black, R.; Bennett, S.R.G.; Thomas, S.M.; Beddington, J.R. Climate change: Migration as adaptation. *Nature* **2011**, *478*, 447–449. [CrossRef] [PubMed]
76. Weitzman, M.L. Fat-tailed uncertainty in the economics of catastrophic climate change. *Rev. Environ. Econ. Policy* **2011**, *5*, 275–292. [CrossRef]
77. Landsea, C.W. A climatology of intense (or major) Atlantic hurricanes. *Mon. Weather Rev.* **1993**, *121*, 1703–1713. [CrossRef]
78. Landsea, C.W.; Anderson, C.; Charles, N.; Clark, G.; Dunion, J.; Fernandez-Partagas, J.; Hungerford, P.; Neumann, C.; Zimmer, M. The Atlantic hurricane database re-analysis project: Documentation for the 1851–1910 alterations and additions to the HURDAT database. In *Hurricanes and Typhoons: Past, Present and Future*; Murnane, R.J., Liu, K.-B., Eds.; Columbia University Press: New York, NY, USA, 2004; pp. 177–221.
79. Elsner, J.B.; Kossin, J.P.; Jagger, T.H. The increasing intensity of the strongest tropical cyclones. *Nature* **2008**, *455*, 92–95. [CrossRef]

Annex 548

K. Gillingham, "Carbon Calculus", *Finance & Development*, 2019, pp. 7-11



CARBON CALCULUS

For deep greenhouse gas emission reductions, a long-term perspective on costs is essential

Kenneth Gillingham

The scientific consensus is clear: climate change is associated with increasingly frequent and intense natural disasters ranging from droughts and wildfires to hurricanes and coastal flooding. While the extent of the economic damage cannot be known for certain, strong evidence suggests it could be quite severe. The challenge for policymakers will be to decide how much to spend on measures to reduce greenhouse gas emissions. To do that, they must be able to compare the costs of various options, including renewable-energy sources and electric cars.

The challenge is taking on increasing urgency in the policy world as climate scientists argue that emission reductions must be rapid and deep, with a goal of reaching net zero by 2050, if not sooner (Millar and others 2017). That goal, which many countries have already embraced, will require a vast transformation of the energy sources used to power the global economy, and it would mean going far beyond

> Some activities that appear expensive in the short term may actually turn out to be low-cost approaches in the long term, because of induced innovation.

business-as-usual technological progress. Indeed, the US Energy Information Administration's *International Energy Outlook 2019* projects that fossil fuels will still generate 57 percent of electricity in 2050.

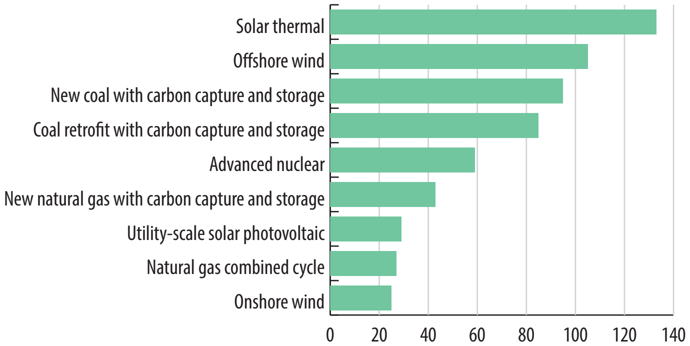
How much would it cost to move beyond business as usual and come within striking distance of net-zero emissions by 2050? To answer this question, it's important to distinguish between short- and long-term costs. In the short term, there are some inexpensive ways to reduce emissions, but deeper cuts run up against quickly rising costs. However, some activities—especially those involving fledgling low-carbon technologies—that appear expensive in the short term may actually turn out to be low-cost approaches in the long term, because of induced innovation. This insight suggests that the longer-term cost of mitigation may be lower than is widely assumed.

Chart 1

Comparing costs

Renewable-energy technologies are among the least costly relative to existing coal generation.

(Dollars per ton of carbon dioxide, in 2017 dollars)



Source: Kenneth Gillingham and James H. Stock, "The Cost of Reducing Greenhouse Gas Emissions," *Journal of Economic Perspectives* 32, no. 4 (Fall 2018): 53–72.
Note: Estimates are derived from the US Energy Information Administration's *Annual Energy Outlook* 2018. Costs are projected for facilities that come online in 2022. Costs do not include federal renewable-energy tax credits or other subsidies.

Short-term costs of technologies

To calculate the short-term costs of mitigating greenhouse gas emissions, economists estimate the up-front costs and divide by the number of tons of carbon dioxide (or equivalent) emissions reduced. For example, suppose a government spends $20 million to promote the development of wind farms to generate electricity, reducing carbon dioxide emissions by 1 million tons. The short-term cost of the mitigation would be $20 per ton. This method provides a useful way of comparing the costs of various ways of reducing emissions.

Of course, one must be cautious in interpreting results focused on an individual technology or policy in isolation. For instance, there could be interactions among policies, and the costs associated with technologies may vary by location and exactly how the technology is implemented. And estimates of such costs are changing every year. Indeed, the cost of solar and wind generation has declined rapidly over the past decade, and the decline appears likely to continue.

My colleague James Stock and I estimated the unsubsidized costs of various technologies to reduce greenhouse gas emissions based on a review of recent economic literature and the Energy Information Administration's *Annual Energy Outlook 2018* (Chart 1). The costs are expressed in relation to existing coal generation, which is a useful benchmark because coal is the most carbon-intensive fuel. In many countries, policymakers will have to decide whether to close existing coal plants on the path toward decarbonization. These estimates are averages from the United States, and one should be cautious in applying them elsewhere.

The most striking takeaway is that renewable-energy technologies are among the least costly. (This result *can* be applied outside the United

States, because markets for most renewable technologies are global.) In fact, the cost of wind and solar may be even lower when implicit or explicit subsidies are included. However, these estimates do not account for the intermittency of renewable energy generation—after all, the sun does not shine and wind does not blow all the time (Joskow 2019). At high levels of use, renewables must be complemented with storage technologies such as pumped hydroelectric storage or batteries, or with a form of generation that can quickly fill the gap when the supply of wind or solar power falters.

In the United States, a low-cost, low-carbon alternative to coal is a power plant that incorporates both gas and steam turbines to increase efficiency. Known as natural gas combined-cycle generation, this solution takes advantage of the copious supply of inexpensive fracked shale gas. One caveat: the estimated cost of $27 per ton assumes that no methane leaks from wells, pipelines, or storage facilities. Methane is a potent greenhouse gas, and the gigantic leak at Aliso Canyon, California, in 2015 shows that natural-gas generation may produce higher greenhouse gas emissions—and thus higher costs per ton of all greenhouse gases reduced.

Social cost

To understand how sensible it is to spend money on these emissions reductions, we can compare them to estimates of carbon's social cost, which quantifies the incremental damage resulting from emitting a ton of carbon dioxide and other greenhouse gases into the atmosphere. This incremental damage includes factors such as losses (or gains in northern climates) to agriculture caused by global warming, flooding from sea level rise, and destruction from more-severe tropical cyclones and additional wildfires. The administration of US President Barack Obama developed a central-case estimate of $50 per ton of carbon dioxide in 2019.

Several technologies for mitigation turn out to be less expensive than carbon when this estimate of carbon's social cost is used (suggesting they are no-brainers), while others are more expensive, such as solar thermal and offshore wind. Benchmarks other than the $50 per ton estimate may also be useful. For instance, a recent IMF report estimates that a tax of $75 per ton of carbon dioxide applied around the world would make it possible to meet the Paris Agreement target of limiting global warming to 2°C over preindustrial

Table 1

Wide range

Economic studies show that costs of short-term measures to reduce carbon dioxide emissions vary widely.

POLICY MEASURE	ESTIMATED COST OF REDUCING CARBON DIOXIDE EMISSIONS (2017 DOLLARS PER TON)
Behavioral energy efficiency	–190
Corn starch ethanol	–18–+310
Reforestation	1–10
Renewable-portfolio standards	0–190
Corporate Average Fuel Economy (CAFE) standards	–110–+310
Wind energy subsidies	2–260
Clean power plants	11
Gasoline taxes	18–47
Methane-flaring regulations	20
Reducing federal coal leasing	33–68
Agricultural emission policies	50–65
National clean energy standards	51–110
Soil management	57
Livestock management policies	71
Concentrating solar power expansion	100
Renewable fuel subsidies	100
Low-carbon fuel standards	100–2,900
Solar photovoltaic system subsidies	140–2,100
Biodiesel	150–420
Energy efficiency programs	250–300
Cash for clunkers	270–420
Weatherization assistance programs	350
Dedicated-battery electric-vehicle subsidies	350–640

Source: Kenneth Gillingham and James H. Stock, "The Cost of Reducing Greenhouse Gas Emissions," *Journal of Economic Perspectives* 32, no. 4 (Fall 2018): 53–72.

Note: The policies in the table are from around the world, but most are from the United States. Costs for greenhouse gases other than carbon dioxide are converted to carbon dioxide equivalents based on the gases' global warming potential. Estimates are based either on individual studies or on a range of estimates from different studies.

levels. If this $75 estimate is used instead of $50, advanced nuclear becomes another option that is less expensive than carbon's social cost.

Short-term costs of policies

So far, we have looked at the costs today of unsubsidized *technologies*, which is useful for understanding the direction markets will be going in the near future. It is clear that as old generation plants are retired and new ones are built, there will be a shift toward renewable-energy technologies, regardless of policy. However, this switch may be much slower than would otherwise be dictated by the ambitious goals many governments have set. So it is also important to understand the costs of emission reductions resulting from different *policy* measures governments could undertake.

A look at studies in the economics literature reveals an extremely wide range of costs for policies that have been implemented and evaluated (Table 1). At the low end are energy efficiency interventions, which actually save money. In behavioral economics, these are often referred to as "nudges," because they simply involve providing or reframing information to influence, or nudge, energy-consumption-related decisions toward a more environmentally friendly approach. A well-known example are reports included in electricity bills that compare a household's electricity use with that of its neighbors. Such interventions are inexpensive and can reduce electricity use by about 2 percent, yielding net savings. While these measures may pay for themselves, the resulting emission reductions tend to be modest and have a relatively small role in deeper decarbonization efforts.

At the high-cost end are many policies that appear to be quite expensive when looking at short-run, static costs. Most notable are policies to induce additional renewable generation and to help decarbonize transportation. In fact, the most expensive are subsidies for electric vehicles. This is because in many places, such vehicles are charged using electricity from fossil fuel sources, which reduces potential emission savings.

Yet such technologies may ultimately be cheaper than the table's short-term estimates suggest. That's because many may provide side benefits such as reduced air pollution, which could make them attractive even if they entail high carbon emission-reduction costs. Moreover, in the longer term, their resulting emission reductions and cost per ton reduced may look very different, owing to spillovers from induced technological change.

Long-term, dynamic costs

Why do innovation spillovers make a difference? Climate change is a long-term, intergenerational problem, with carbon dioxide in the atmosphere persisting for hundreds to thousands of years. Thus, technological change and innovation are central to longer-term efforts to mitigate climate change by developing alternatives to fossil fuels. While technologies to steeply reduce emissions are available today, there is not only tremendous inertia in the energy system, but also much room for further cost declines in the technology. These considerations lend themselves to a long-term, dynamic perspective that accounts for how spending on new technologies today may lower the cost of reducing emissions in the future.

There are several reasons why taking the longer-run, dynamic perspective makes sense. Economists know that research and development generates spillovers because firms often can only partly appropriate the gains it brings. For example, once a patent expires, any firm can take advantage of the associated innovation. There may also be cases where engineering and managerial improvements from producing a new technology lower the technology's costs (often called "learning by doing"), and some of the cost reductions may spill over to other firms. For instance, there is evidence that firms in the semiconductor industry lowered their production costs as they produced more of each generation of semiconductors and that these lowered costs spilled over to other firms (Irwin and Klenow 1994). There may also be positive network effects, with benefits to society from the adoption of a single standard, such as one plug that works for charging all electric vehicles. All three types of spillovers allow other firms to reduce costs, improving social welfare and providing an economic motivation for carefully designed policies to foster such spillovers.

Apart from spillovers, recent work in the economics of clean-energy innovation has emphasized that optimal policy may be quite different in the long term simply because expenditures today may have long-term effects. Some of the approaches to reducing emissions that are more expensive in the short term may spur innovation that could lead to lower long-term costs than existing approaches. Consider

Technological change and innovation are central to longer-term efforts to mitigate climate change by developing alternatives to fossil fuels.

subsidies for electric vehicles, which include rapidly improving technology such as batteries. If policy today for clean technology can reduce costs substantially in the future, then it may make sense to undertake more expensive options today (Acemoglu and others 2016; Vogt-Schilb and others 2018). In principle, this finding holds even if only a single firm adopts the low-carbon innovation (so there would be no innovation spillovers), although in practice there will almost certainly be spillovers leading to lower long-term costs. The key insight is that when society chooses how best to address climate change, the optimal long-term decision may differ from the short-term, myopic decision. Of course, it is not easy to foresee how technology will unfold, so any decision involves uncertainty. But we know that mature technologies are less likely to see major leaps than nascent ones. Thus, the long-term view applies only to newer low-carbon technologies with real potential to reduce costs in the future.

Game changers

Let's return to our original question. Is it possible to decarbonize deeply enough to come within striking distance of net-zero greenhouse gas emissions by 2050? Yes, it is feasible even today—the technologies exist. Yet such a vast transformation of the energy system will be costly and challenging if attempted all at once, especially considering the large short-term costs of the transition for fossil-fuel-reliant developing nations. There are certainly inexpensive measures that can be implemented today, including energy conservation, efficiency nudges, and the replacement of retiring fossil-fuel powered electricity generation with renewables. The costs of these measures are already lower than the damage from climate change they would avert, based on estimates of carbon's social cost. But many other approaches are quite costly in the short term, especially efforts to promote new low-carbon technologies. However, when the policies have strong potential to spur innovation, they may lead to much lower total costs over the longer term.

A long-term perspective that keeps innovation in mind is crucial in considering ways to tackle climate change. Innovations such as small modular nuclear reactors and carbon capture technologies could be game changers in achieving net-zero greenhouse gas emissions at a low cost. Granted, as the Danish physicist Niels Bohr said, "prediction is very difficult, especially if it is about the future." The future path of technology is unknown, so we can at best speculate about the ultimate cost of reaching net zero. Yet we can plan for the future without regret by providing incentives for both low-cost greenhouse gas mitigation and low-carbon innovation, such as economy-wide carbon pricing, while also judiciously investing in new technologies. FD

KENNETH GILLINGHAM is an associate professor of environmental and energy economics at Yale University. This article is adapted from a 2018 article he wrote with James H. Stock, "The Cost of Reducing Greenhouse Gas Emissions," published in the *Journal of Economic Perspectives*.

References

Acemoglu, Daron, Ufuk Akcigit, Douglas Hanley, and William Kerr. 2016. "Transition to Clean Technology." *Journal of Political Economy* 124, no. 1: 52–104. https://www.journals.uchicago.edu/doi/abs/10.1086/684511

Irwin, Douglas, and Peter Klenow. 1994. "Learning-by-Doing Spillovers in the Semiconductor Industry." *Journal of Political Economy* 102, no. 6: 1200–27. https://doi.org/10.1086/261968

Joskow, Paul L. 2019. "Challenges for Wholesale Electricity Markets with Intermittent Renewable Generation at Scale: The US Experience." *Oxford Review of Economic Policy* 35, no. 2: 291–331. https://doi.org/10.1093/oxrep/grz001

Millar, Richard J., Jan S. Fuglestvedt, Pierre Friedlingstein, and others. 2017. "Emission Budgets and Pathways Consistent with Limiting Warming to 1.5°C." *Nature Geoscience* 10: 741–47. https://www.nature.com/articles/ngeo3031

Vogt-Schilb, Adrian, Guy Meunier, and Stephane Hallegatte. 2018. "When Starting With the Most Expensive Option Makes Sense: Optimal Timing, Cost and Sectoral Allocation of Abatement Investment." *Journal of Environmental Economics and Management* 88: 210–33. https://doi.org/10.1016/j.jeem.2017.12.001

Annex 549

P. Grippa et al., “Climate Change And Financial Risk”, *Finance & Development*, 2019, pp. 26-29

Climate Change and FINANCIAL RISK

Central banks and financial regulators are starting to factor in climate change

Pierpaolo Grippa, Jochen Schmittmann, and Felix Suntheim

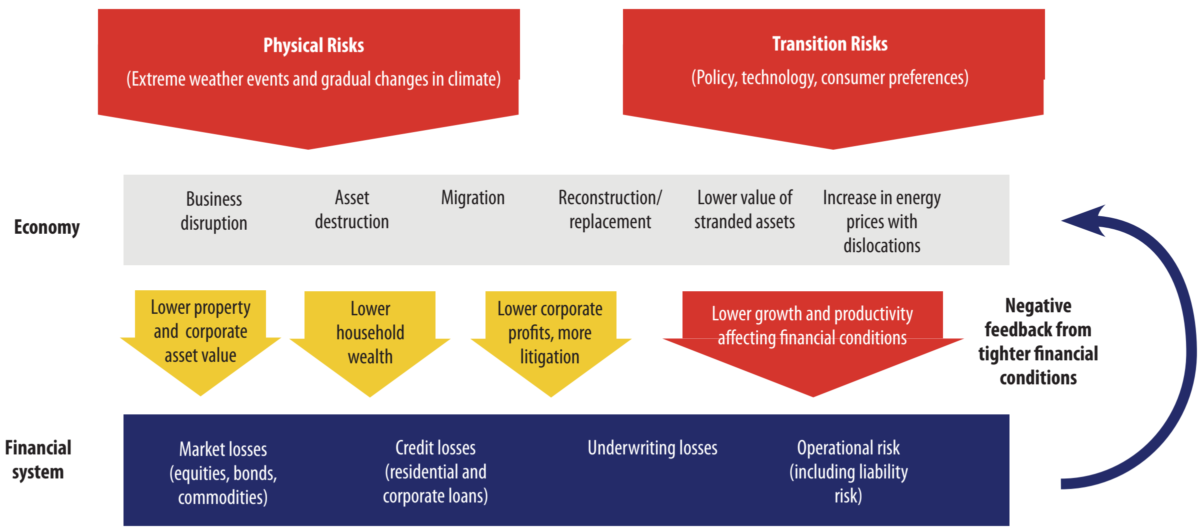
Climate change is already a reality. Ever-more-ferocious cyclones and extended droughts lead to the destruction of infrastructure and the disruption of livelihoods and contribute to mass migration. Actions to combat rising temperatures, inadequate though they may have been so far, have the potential to drive dislocation in the business world as fossil fuel giants awaken to the need for renewable sources of energy and automakers accelerate investments in cleaner vehicles.

But measuring economic costs of climate change remains a work in progress. We can assess the immediate costs of changing weather patterns and more frequent and intense natural disasters, but most of the potential costs lie beyond the horizon of the typical economic analysis. The economic impact of climate change will likely accelerate, though not smoothly. Crucially for the coming generations, the extent of the damage will depend on policy choices that we make today.

Policymakers and investors increasingly recognize climate change's important implications for the financial sector. Climate change affects the financial system through two main channels (see Chart 1). The first involves physical risks, arising from damage to property, infrastructure, and land. The second, transition risk, results from changes in climate policy, technology, and consumer and market sentiment during the adjustment to a lower-carbon economy. Exposures can vary significantly from country to country. Lower- and

Physical and transition risks

The risks from climate change to the economy have two basic channels, but many potential impacts.



middle-income economies are typically more vulnerable to physical risks.

For financial institutions, physical risks can materialize directly, through their exposures to corporations, households, and countries that experience climate shocks, or indirectly, through the effects of climate change on the wider economy and feedback effects within the financial system. Exposures manifest themselves through increased default risk of loan portfolios or lower values of assets. For example, rising sea levels and a higher incidence of extreme weather events can cause losses for homeowners and diminish property values, leading to greater risks in mortgage portfolios. Corporate credit portfolios are also at risk, as highlighted by the bankruptcy of California's largest utility, Pacific Gas and Electric. In what *The Wall Street Journal* called the first "climate-change bankruptcy" (Gold 2019), rapid climatic changes caused prolonged droughts in California that dramatically increased the risk of fires from Pacific Gas and Electric's operations. Tighter financial conditions might follow if banks reduce lending, in particular when climate shocks affect many institutions simultaneously.

For insurers and reinsurers, physical risks are important on the asset side, but risks also arise from the liability side as insurance policies generate claims with a higher frequency and severity than originally expected. There is evidence that losses from natural disasters are already increasing. As a result, insurance is likely to become more expensive or even unavailable in at-risk areas of the world. Climate change can make banks, insurers, and reinsurers less diversified, because it can increase the likelihood or impact of events previously considered uncorrelated, such as droughts and floods.

Transition risks materialize on the asset side of financial institutions, which could incur losses on exposure to firms with business models not built around the economics of low carbon emissions. Fossil fuel companies could find themselves saddled with reserves that are, in the words of Bank of England Governor Mark Carney (2015), "literally unburnable" in a world moving toward a low-carbon global economy. These firms could see their earnings decline, businesses disrupted, and funding costs increase because of policy action, technological change, and consumer and investor demands for alignment with policies to tackle climate change. Coal producers, for example, already grapple with new or expected policies curbing carbon emissions, and a number of large banks have pledged not to provide financing for new coal facilities. The share prices of US coal mining companies reflect this "carbon discount" as well as higher financing costs and have been underperforming relative to those of companies holding clean energy assets.

Risks can also materialize through the economy at large, especially if the shift to a low-carbon economy proves abrupt (as a consequence of prior inaction), poorly designed, or difficult to coordinate globally (with consequent disruptions to international trade). Financial stability concerns

ART: ISTOCK/ROMEOCANE1

arise when asset prices adjust rapidly to reflect unexpected realizations of transition or physical risks. There is some evidence that markets are partly pricing in climate change risks, but asset prices may not fully reflect the extent of potential damage and policy action required to limit global warming to 2°C or less.

Central banks and financial regulators increasingly acknowledge the financial stability implications of climate change. For example, the Network of Central Banks and Supervisors for Greening the Financial System (NGFS), an expanding group that currently comprises 48 members, has embarked on the task of integrating climate-related risks into supervision and financial stability monitoring.

Given the large shifts in asset prices and catastrophic weather-related losses that climate change may cause, prudential policies should adapt to recognize systemic climate risk—for example, by requiring financial institutions to incorporate climate risk scenarios into their stress tests. In the United Kingdom, prudential regulators have incorporated climate change scenarios into stress tests of insurance firms that cover both physical and transition risks.

Efforts to incorporate climate-related risks into regulatory frameworks face important challenges, however. Capturing climate risk properly requires assessing it over long horizons and using new methodological approaches, so that prudential frameworks adequately reflect actual risks. It is crucial to ensure that the efforts to bring in climate risk strengthen, rather than weaken, prudential regulation. Policies such as allowing financial institutions to hold less capital against debt simply because the debt is labeled as green could easily backfire—through increased leverage and financial instability—if the underlying risks in that debt have not been adequately understood and measured.

Climate change will affect monetary policy, too, by slowing productivity growth (for example, through damage to health and infrastructure) and heightening uncertainty and inflation volatility. This can justify the adaptation of monetary policy to the new challenges, within the limits of central bank mandates. Central banks should revise the frameworks for their refinancing operations to incorporate climate risk analytics, possibly applying larger haircuts to assets materially exposed to physical or transition risks. Central banks can also lead by example by integrating sustainability considerations into the investment decisions for the portfolios under their management (i.e., their own funds, pension funds and, to the extent possible, international reserves), as recommended by the NGFS (2019) in its first comprehensive report.

Financial sector contribution

Carbon pricing and other fiscal policies have a primary role in reducing emissions and mobilizing revenues (see "Putting a Price on Pollution" in this issue of F&D), but the financial sector has an important complementary role. Financial institutions and markets already provide financial protection through insurance and other risk-sharing mechanisms, such as catastrophe bonds, to partly absorb the cost of disasters.

But the financial system can play an even more fundamental role, by mobilizing the resources needed for investments in climate mitigation (reducing greenhouse gas emissions) and adaptation (building resilience to climate change) in response to price signals, such as carbon prices. In other words, if policymakers implement policies to price in externalities and provide incentives for the transition to a low-carbon economy, the financial system can help achieve these goals efficiently. Global investment requirements for addressing climate change are estimated in the trillions of US dollars, with investments in infrastructure alone requiring about $6 trillion per year up to 2030 (OECD 2017). Most of these investments are likely to be intermediated through the financial system. From this point of view, climate change represents for the financial sector as much a source of opportunity as a source of risk.

The growth of sustainable finance (the integration of environmental, social, and governance criteria into investment decisions) across all asset classes shows the increasing importance that investors attribute to climate change, among other nonfinancial considerations. Estimates of the global asset size of sustainable finance range from $3 trillion to $31 trillion. While sustainable investing started in equities, strong investor demand and policy support spurred issuance of green bonds, growing the stock to an estimated $590 billion in August 2019 from $78 billion in 2015. Banks are also beginning to adjust their lending policies by, for example, giving discounts on loans for sustainable projects.

Sustainable finance can contribute to climate change mitigation by providing incentives for firms to adopt less carbon-intensive technologies and specifically financing the development of new technologies. Channels through which investors can achieve this goal include engaging with company management, advocating for low-carbon strategies as investor activists, and lending to firms that are leading in regard to sustainability. All these actions send price signals, directly and indirectly, in the allocation of capital.

However, measuring the impact that sustainable investments have on their environmental targets remains challenging. There are concerns over unsubstantiated claims of assets' green-compliant nature, known as "greenwashing." There is a risk that investors may become reluctant to invest at the scale necessary to counter or mitigate climate change, especially if policy action to address climate change is lagging or insufficient.

The IMF's role

The analysis of risks and vulnerabilities—and advising its members on macro-financial policies—are at the core of the IMF's mandate. The integration of climate change risks into these activities is critical given the magnitude and global nature of the risks climate change is posing to the world.

An area where the IMF can especially contribute is understanding the macro-financial transmission of climate risks. One aspect of this is further improving stress tests, such as those within the Financial Sector Assessment Program, the IMF's comprehensive and in-depth analysis of member countries' financial sectors.

Stress testing is a key component of the program, with these stress tests often capturing the physical risks related to disasters, such as insurance losses and nonperforming loans associated with natural disasters. Assessments for The Bahamas and Jamaica are recently published examples, with a scenario-based stress test analyzing the macroeconomic impact of a severe hurricane in the former and a massive natural disaster in the latter. More assessments of this kind are in progress or planned for other countries. The IMF is also conducting an analysis of financial system exposure to transition risk in an oil-producing country.

The IMF has recently joined the NGFS and is collaborating with its members to develop an analytical framework for assessing climate-related risks.

Closing data gaps is also crucial. Only with accurate and adequately standardized reporting of climate risks in financial statements can investors discern companies' actual exposures to climate-related financial risks. There are promising efforts to support private sector disclosures of such risks. But these disclosures are often voluntary and uneven across countries and asset classes. Comprehensive climate stress testing by central banks and supervisors would require much better data. The IMF supports public and private sector efforts to further spread the adoption of climate disclosures across markets and jurisdictions, particularly by following the recommendations of the Task Force on Climate-related Financial Disclosures (2017). Greater standardization would also improve the comparability of information in financial statements on climate risks.

The potential impact of climate change compels us to think through, in an empirical fashion, the economic costs of climate change. Each destructive hurricane and every unnaturally parched landscape will chip away at global output, just as the road to a low-carbon economy will escalate the cost of energy sources as externalities are no longer ignored and old assets are rendered worthless. On the other hand, carbon taxes and energy-saving measures that reduce the emission of greenhouse gases will drive the creation of new technologies. Finance will have to play an important role in managing this transition, for the benefit of future generations. FD

PIERPAOLO GRIPPA is a senior economist and **FELIX SUNTHEIM** is a financial sector expert in the IMF's Monetary and Capital Markets Department. **JOCHEN SCHMITTMANN** is the IMF's resident representative in Singapore.

This article draws on Chapter 6 of the October 2019 Global Financial Stability Report *and was prepared under the guidance of Martin Čihák and Evan Papageorgiou of the IMF's Monetary and Capital Markets Department.*

References:

Carney, Mark. 2015. "Breaking the Tragedy of the Horizon—Climate Change and Financial Stability." Speech delivered at Lloyd's of London, September 29. https://www.bankofengland.co.uk/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability

Gold, Russell. 2019. "PG&E: The First Climate-Change Bankruptcy, Probably Not the Last." *Wall Street Journal*, January 18. https://www.wsj.com/articles/pg-e-wildfires-and-the-first-climate-change-bankruptcy-11547820006

NGFS (Network of Central Banks and Supervisors for Greening the Financial System). 2019. *A Call for Action: Climate Change as a Source of Financial Risk.* Paris: NGFS Secretariat. https://www.ngfs.net/en/first-comprehensive-report-call-action

OECD (Organisation for Economic Co-operation and Development). 2017. *Investing in Climate, Investing in Growth.* Paris: OECD Publishing. http://dx.doi.org/10.1787/9789264273528-en

Task Force on Climate-related Financial Disclosures. 2017. *Final Report: Recommendations of the Task Force on Climate-related Financial Disclosures.* Basel. https://www.fsb-tcfd.org/publications/final-recommendations-report/

Annex 550

G. Kling et al., “The impact of climate vulnerability on firms’ cost of capital and access to finance”, *World Development*, 2021

World Development 137 (2021) 105131

Contents lists available at ScienceDirect

World Development

journal homepage: www.elsevier.com/locate/worlddev

The impact of climate vulnerability on firms' cost of capital and access to finance

Gerhard Kling [a,b], Ulrich Volz [b,c,d,*], Victor Murinde [b,e], Sibel Ayas [e]

[a] University of Aberdeen Business School, King's College, Aberdeen AB24 3FX, UK
[b] Centre for Sustainable Finance, SOAS University of London, Thornhaugh Street, London WC1H 0XG, UK
[c] Department of Economics, SOAS University of London, Thornhaugh Street, London WC1H 0XG, UK
[d] German Development Institute, Tulpenfeld 6, 53113 Bonn, Germany
[e] School of Finance and Management, SOAS University of London, Thornhaugh Street, London WC1H 0XG, UK

ARTICLE INFO

Article history:
Available online 25 August 2020

JEL codes:
Q54
O16
G32

Keywords:
Climate vulnerability
Cost of capital
Access to finance
Financial exclusion

ABSTRACT

This article presents the first systematic investigation of the effects of climate-related vulnerability on firms' cost of capital and access to finance and sheds light on a hitherto under-appreciated cost of climate change for climate vulnerable developing economies. We first show theoretically how climate vulnerability could affect firms' cost of capital and access to finance. Apart from a possible impact on cost of debt and equity, which drive cost of capital, firms in countries with high exposure to climate risk might be more financially constrained. The latter results in low levels of debt relative to total assets or equity due to restricted access to finance. We then examine this issue empirically, using panel data of 15,265 firms in 71 countries over the period 1999–2017. We invoke panel data regressions and structural equation models, with firm-level data from the Thomson Reuters Eikon database and different measures of climate vulnerability based on the ND-GAIN climate vulnerability index. We construct a new climate vulnerability index and use panel instrumental variable regressions to address endogeneity problems. Our empirical findings suggest that climate vulnerability increases cost of debt directly and indirectly through its impact on restricting access to finance. However, we find limited evidence that climate vulnerability affects cost of equity. Our estimations suggest that the direct effect of climate vulnerability on the average increase in cost of debt from 1991 to 2017 has been 0.63%. In addition, the indirect effect through climate vulnerability's impact on financial leverage has contributed an additional 0.05%.

1. Introduction

Climate change is having real impact on economies already. Indeed, the frequency of natural disasters such as droughts, extreme temperatures, floods, landslides and storms, is on the rise (IPCC, 2018). This dramatic increase in climate change-related catastrophes translates into enormous economic costs. The direct impact of catastrophic natural disasters on economies is empirically well established (e.g., Cavallo, Galiani, Noy, & Pantano, 2013; Felbermayr & Gröschl, 2014; Ferreira & Karali, 2015; Mendelsohn, Kerry, Chonabayashi, & Bakkensen, 2015; Alano & Lee, 2016; Botzen, Deschenes, & Sanders, 2019). Moreover, both gradual global warming and natural disasters are associated with significant negative effects on long-run economic growth (e.g., Burke, Hsiang, & Miguel, 2015; Klomp & Valckx, 2014; Kompas, Pham, & Che, 2018; Kahn et al., 2019). Although impacts differ across countries, there is a consensus that the biggest impacts of climate change are being felt in developing countries.

One interesting dimension of these economic costs relates to recent empirical evidence by Kling, Lo, Murinde, and Volz (2018) that climate vulnerability increases the cost of sovereign borrowing: vulnerability to climate risks, as measured by the Notre-Dame Global Adaptation Initiative (ND-GAIN) sub-indices for climate sensitivity and capacity, has increased sovereign cost of debt by 1.17 percentage points on average for climate vulnerable developing countries over the last decade. The cost at which governments can access finance affects public budgets and governments' ability to invest in climate mitigation and adaptation; it also constrains possible investments in areas such as infrastructure, education and public health.

* Corresponding author at: Department of Economics, SOAS University of London, UK

E-mail addresses: gerhard.kling@abdn.ac.uk (G. Kling), uv1@soas.ac.uk (U. Volz), vm10@soas.ac.uk (V. Murinde), ayassibel@gmail.com (S. Ayas).

https://doi.org/10.1016/j.worlddev.2020.105131
0305-750X/© 2020 The Authors. Published by Elsevier Ltd.

This study explores a related and equally interesting question: how does climate vulnerability affect the private sectors' cost of capital and access to finance? In a recent attempt to address related issues, Huang, Kerstein, and Wang (2018) investigate the effect of climate-related risk on financing choices by publicly listed firms covering 54 countries from 1993 to 2012. They find that firms located in climate vulnerable countries anticipate the likelihood of losses from major storms, flooding, heat waves, and other adverse weather conditions by holding more cash, less short-term debt but more long-term debt, and are less likely to distribute cash dividends. Moreover, firms in certain industries are less vulnerable to extreme weather and so face less climate-related risks. However, the more directly relevant question is whether climate vulnerability increases firms' cost of capital and affects their access to finance. The latter is not covered by Huang et al. (2018) as they regard a firms' financing decision as a choice and not a consequence of being financially excluded.

This article examines the alleged impact of climate vulnerability on cost of capital first theoretically, identifying the main channels through which an effect can materialise. In summary, cost of capital refers to a weighted average of cost of debt and cost of equity. The weights represent the proportion of debt and equity finance. Theoretically, we outline how climate vulnerability can change cost of debt and equity. Finally, climate risks can contribute to financial exclusion as additional risks might make loans unviable for banks. Usually banks can charge higher interest rates to cover expected losses; however, frequent climate events might affect their abilities to predict outcomes and might make firms more vulnerable to higher interest rates, leading to credit rationing. Hence, the pricing mechanism can fail as shown theoretically by Kling (2018).

Empirically, this article tests these theoretical predictions using a large-scale panel dataset covering 15,265 firms in 71 countries over the period 1999–2017. First, we show that the ND-GAIN climate vulnerability index, the most widely used measure of climate vulnerability, is endogenous due to its close relationship with economic variables. Hence, to assess the impact of climate vulnerability on cost of capital, an instrument is needed. From raw data used by ND-GAIN to construct their indices, we redesign an index less correlated with macroeconomic variables. Second, we derive initial results for cost of debt and equity using panel instrumental variable regressions. Climate vulnerability does increase cost of debt – but not cost of equity. Third, to account for the alleged impact of climate vulnerability on access to finance and high correlations between GDP per capita and governance measures, we specify structural equation models. These reveal a direct effect of climate vulnerability in line with our instrumental variable approach – but also show an indirect effect as firms located in countries with high climate related risks exhibit restricted access to finance.

The analysis sheds light on a hitherto under-appreciated cost of climate change for climate vulnerable developing economies: higher corporate financing cost and financial exclusion. Both factors hold back economic development and by restraining fiscal revenue limit the scope of governments to invest in public (climate resilient) infrastructure and climate adaptation. Underinvestment in turn curbs growth prospects and puts firms in climate vulnerable developing economies at a disadvantage when competing in both domestic and export markets. In other words, the climate vulnerability risk premium causes a vicious circle, where a higher cost of capital reduces both sovereign and private sector investment, suppresses firm growth and tax revenue, and limits the scope for public adaptation finance.

The article is structured as follows. Section 2 reviews prior research. Section 3 then discusses theoretically the effect of climate vulnerability on firms' cost of capital as well as financial exclusion of firms. Section 4 provides an overview of the sample, the construction of variables, and a discussion of the ND-GAIN climate vulnerability index. Section 5 shows our empirical findings including descriptive statistics, endogeneity tests, panel instrumental variable regressions, and structural equation models. Finally, Section 6 concludes.

2. Prior research

The economic impact of climate change on both countries and corporations is complex and sometimes ambivalent. Several studies have investigated the relationship between global climate change and economic performance at the country-level (e.g., Dell, Jones, & Olken, 2014; Nordhaus, 2006). In addition, studies have also examined the influence of climate change on firm-level performance. Climate change may impact businesses from any industry and size. Firms may face several climate-related risks such as emission-reduction regulation and negative reactions from environmentally concerned investors or lenders. For instance, Beatty and Shimshack (2010) explore the relationship between greenhouse gas emissions and stock market returns. They find that some investors tend to react adversely to new information about greenhouse gas emissions, leading to a substantial decrease in stock market valuation between 0.6 and 1.6 percent. Another study by Konar and Cohen (2001) reports that bad environmental performance is negatively associated with the value of intangible assets of firms.

Even if government regulations intended to curtail greenhouse gas emissions are not currently introduced in every country, it may be a significant indicator for environmentally sensitive investors and lenders which increasingly demand more disclosure from firms. Matsumura, Prakash, and Vera-Munoz (2013) collect carbon emissions data from S&P 500 firms over the period 2006–2008 and find a negative relationship between carbon emissions and firm value. Their results suggest that firm value might fall by USD 212,000 for every additional thousand metric tons of carbon emissions.

Investors are increasingly considering environmental, social and governance (ESG) performance of businesses before they take investment decisions. Using data for 13,114 firms for the period 1992–2007, Chava (2014) identifies the effect of firms' environmental profile on their cost of equity and debt capital. According to this research, investors require higher expected returns from companies that are less concerned about climate change. Furthermore, Chava (2014) also finds that lenders charge a significantly lower interest rate on bank loans to environmentally responsible firms. More recently, Huang et al. (2018) analyse a dataset comprising 353,906 observations from 54 countries and find that climate risk at country level, measured by Germanwatch's Global Climate Risk Index which is based on economic losses and fatalities from extreme weather events, might be negatively related to firm earnings and positively related to earnings volatility. Previous research has also indicated that various environmental indicators have a positive impact on firms' cost of capital. Sharfman and Fernando (2008) examine data from 267 U.S. firms and assert that there is a negative relationship between environmental risk management and cost of capital, suggesting that better environmental risk management contributes to reducing firms' cost of equity.

El Ghoul, Guedhami, Kwok, and Mishra (2011) analyse data from 12,915 firms between 1992 and 2007 and find that corporate social responsibility (CSR) practices have an influence on equity financing. Dealing with employee relations and environmental issues decreases firms' cost of equity. Similarly, Dhaliwal, Li, Tsang, and Yang (2011) find a negative association between voluntary disclosure of CSR activities and firms' cost of equity capital.

Therefore, this may draw more attention of institutional investors and analyst coverage.

Climate risks are increasingly recognized as a serious and worldwide concern for both governments and businesses. This is also reflected by a growing number of financial supervisors who are calling on financial firms and corporations to disclose climate-related financial risks (Monasterolo, Battiston, Janetos, & Zheng, 2018). However, much uncertainty still exists about the relation between climate risks and cost of capital. Although some research has been carried out on the effect of global climate risk on firm performance using cross-country data (Huang et al., 2018), there is very little scientific understanding of the impact of climate risk as a determinant of firms' cost of capital and access to finance. This study aims to address this research gap.

3. Theoretical considerations

A firm's cost of capital refers to its weighted average cost of capital (WACC), denoted r_{WACC}, which depends on the proportion of debt finance (D) to debt and equity (D + E), the cost of debt (r_D), the cost of equity (r_E) and the marginal tax rate (τ). The latter matters as interest expenses are tax deductible in some countries, reducing the after-tax cost of capital. Denoting the proportion of debt finance L = D/(D + E), i.e. financial leverage, (1) states the WACC:

$$r_{WACC} = L \cdot r_D \cdot (1-\tau) + (1-L)r_E \tag{1}$$

Due to differences in pay-out profiles, equity holders bear more risk than debt holders, requiring higher expected returns. This implies $r_E > r_D$. It is obvious from (1) that climate vulnerability (VUL) can increase the WACC r_{WACC} in three ways: (1) $\partial L/\partial VUL < 0$ (shift to equity as it is more difficult to secure debt finance, e.g. due to volatile cash flows); (2) $\partial r_D/\partial VUL > 0$ (increased cost of debt); and (3) $\partial r_E/\partial VUL > 0$ (increased cost of equity).

Considering the cost of debt, we can state the following components, where r_f refers to the risk-free rate, d is a default component (credit spread), and l is a liquidity component. The spread s contains the default and liquidity component:

$$r_D = r_f + \Delta INF + \Delta EX + d + l = \sum_{k=1}^{K} c_k D_k + r_f + s \tag{2}$$

The risk-free rate usually refers to the yield of ten-year US government bonds. If debt is taken outside the US, country risk needs to be added (using country dummies D_k with k = 1, 2, ..., K), and the expected difference in inflation should be considered ΔINF. If debt is denominated in a foreign currency, differences in expected inflation should be reflected in exchange rates (purchasing power parity). Thus, an exchange rate effect can be added to (2).

The problem is that, empirically, most of these components cannot be determined due to lack of data. First, credit default swaps (CDS) are not available for most companies; hence, we cannot decompose the spread into a default and liquidity component. This is not a major limitation as working with annual data should suggest a low average liquidity component. Furthermore, the impact of climate vulnerability on default risk is more plausible. Second, financial data does not provide details on USD denominated debt and debt in other currencies. Hence, using country dummies we proxy country risk and other factors such as inflation differentials and exchange rate changes. Alternatively, both factors could be included in an empirical specification. From Eq. (2), climate vulnerability can affect cost of debt in three ways: (1) changing country risk; (2) influencing the risk-free rate, which seems to be less likely; (3) increasing the spread mainly due to higher default risk.

Finally, cost of equity is explained using the capital asset pricing model (CAPM), which links firms' cost of equity to the risk-free rate, the expected market risk premium and systematic risk through the beta coefficient. Note that r_m refers to the market return, and E is the expectations operator:

$$r_E = r_f + \beta(Er_m - r_f) \tag{3}$$

Climate vulnerability can increase cost of equity by (1) shifting the risk-free rate as in the case of cost of debt, (2) changing the market risk premium, and (3) increasing a firm's beta coefficient. The latter point seems to be plausible at first; however, one needs to note that the market return is the sample average return. Thus, the average beta cannot increase due to climate change. Furthermore, there are empirical limitations. First, beta coefficients trend to vary over time. Second, the CAPM has low predictive power in less developed markets. Hence, it might be better to estimate country-level betas using countries' leading stock market index compared to the MSCI world market index.

The arguments thus far implicitly assume that firms have access to finance, i.e. firms have a choice between debt and equity finance reaching their desired leverage L^* and raising their desired level of capital to invest and grow the firm. However, financial inclusion is not guaranteed and potentially itself a function of climate vulnerability. Hence, climate vulnerability might increase cost of debt under the condition that firms have access to finance, and climate vulnerability might contribute to a higher probability to be financially excluded. Financial exclusion can be due to information asymmetry, e.g. banks might struggle to derive expected default risk in countries exposed to high climate risk, but also price sensitivity (Kling, 2018). Basically, if higher interest rates increase default risk (i.e. make liquidity default more likely), it might be impossible to find an optimal interest rate that compensates for the expected default risk. This leads to credit rationing, even in the absence of information asymmetry.

4. Data and variables

4.1. Sampling

Our aim is to assess cost of debt and equity of firms located in countries with varying climate vulnerability. We use firm-level data from the Thomson Reuters Eikon database and try to include as many countries as possible. However, the database does not provide sufficient data for many small countries with high climate risk (e.g. Tuvalu). In particular, we try to cover countries that are members of the Climate Vulnerable Forum, which consists of 48 countries. Larger countries in this group such as Bangladesh, Ghana, Vietnam and Kenya can be included in the sample. For inclusion, we require at least ten companies with financial data in the Thomson Reuters Eikon database. In total, our sample contains 95,037 firm-year observations with 18,431 firm-year observations in countries with high climate vulnerability (see Section 4.2). Our panel dataset contains 15,265 firms from 71 countries after listwise deletion.[1] With 3,683 firms in high-risk countries, our analysis should be able to assess their cost of capital and access to finance.

The sample excludes financial firms as their investment and financing decisions differ from non-financial firms. For instance, deposit taking banks can finance their loan book through customers' savings. In addition, regulation for financial firms is strict and includes minimum equity requirements, which affects standard financial ratios.

[1] We require that the database has information that permits calculating cost of debt, interest coverage, working capital, financial leverage, firm size, dividends, tangible assets, and return on assets.

4.2. Measuring climate vulnerability

Climate vulnerability data are obtained from the Notre Dame Global Adaptation Index (ND-GAIN). This index brings together 74 variables to form 45 core indicators for 181 countries to measure their environmental vulnerability and their readiness to adapt. The technical report outlines the methodology and data sources; hence, we refer to Chen et al. (2015) for a detailed discussion. Our focus is on climate vulnerability, which combines exposure, sensitivity and adaptive capacity. The latter is partly affected by countries' economic, political and social settings. Geography, however, determines a countries' exposure, which is not a matter of choice.

Inherently, climate vulnerability is not independent from macroeconomic conditions, which can cause empirical concerns such as endogeneity (see Section 5.2). This alleged problem is likely to be more pronounced when using the ND-GAIN climate readiness index, which focuses on economic, governance and social measures. These tend to be highly correlated; an issue we address in our structural equation model (see Section 5.5).

Exploring the ND-GAIN climate vulnerability index (VUL) for our sample and period from 1999 to 2017, we must ensure that countries exhibit a sufficient degree of variability. Otherwise, our analysis cannot distinguish between country-level fixed effects (dummies in regressions) and stable climate vulnerability. Fortunately, VUL exhibits some variability over time. For instance, Gambia exhibited an increase of 9.9% from 1995 to 2016, while Mongolia has improved by 15.9% as it benefits from rising temperatures. Section 5.2 explores the ND-GAIN VUL and empirical issues in more detail.

4.3. Construction of variables

The first dependent variable is cost of debt (COD), which we estimate using interest expense in year t divided by total debt reported in period t.[2] To obtain a firm-level proxy for cost of equity (COED), our second dependent variable, we rely on dividend payments relative to the value of equity. In addition, we derive country-level measures of cost of equity (COE) by estimating country betas (BETA) and market risk premiums (MRP). Data for the MRP is obtained from Damodaran (2013). Country betas are estimated using each countries' leading stock market index from which we obtain the stock market return. Countries' stock return is then regressed on the return of the US stock market, which provides an estimate of countries' beta coefficient.

Financial leverage is a standard control variable and measure of financial risk. Leverage (LEV) is calculated as the ratio of a firm's total debt to total assets. Firms with high leverage are highly indebted and hence riskier, resulting in higher cost of debt. However, if firms are financially constrained, i.e. they do not get access to debt finance, this relationship might not hold. For instance, a firm that cannot get a bank loan has low leverage – but it might be still risky. Net operating working capital measures a firm's access to trade credit, which lowers working capital. We measure working capital (WC) as operating current assets minus operating current liabilities. Interest coverage refers to earnings before interest and taxes divided by interest expenses (COVER). A high interest coverage reduces the risk of liquidity default as a firm can use its earnings to pay interest on debt. Firm size (SIZE) is defined as the log of total assets. Additional firm-level controls are dividend payments (DIV), tangible assets (TANG) and return on assets (ROA). All variables on the firm-level are expressed relative to total assets.

Industry controls account for the volatility of cash flows to total assets (VOL) in an industry defined based on two-digit GICS codes. Firms operating in industries most affected by climate risk such as oil, gas, coal, energy & agriculture are flagged with an indicator variable labelled IND RISK. Our definition of industries more exposed to climate risks is partly overlaps with Huang et al. (2018). They use the term 'vulnerable industries', which include energy, oil and food production. They also incorporate business services, communication, health care and transportation. The categories of business services and communication are too broad, and health care and transportation are partly provided by public entities. Consequently, we use a narrower definition of vulnerable industries.

Country controls are based on the World Development Indicators database. We consider the log of GDP per capita in constant 2010 USD, annual GDP per capita growth rate (GROWTH), and population density (POP). To account for the quality of institutions and governance, we include the rule of law (LAW) based on the World Governance Indicators.

Finally, we include annual average rainfall (M RAIN) and temperature (M TEMP) as well as their standard deviations (SD RAIN, SD TEMP) provided by the World Bank. These country-level measures serve as exogenous variables, unaffected by countries' economic condition – but influenced by climate change. To mitigate the impact of outliers, we apply a winsorization to all variables at the 5 and 95-percentile. The Appendix summarises the definitions of variables and data sources.

5. Results

5.1. Descriptive findings

We estimate the cost of debt using interest expenses and total debt reported in firms' balance sheets. Countries that are in the top 25% regarding climate vulnerability are categorized as high-risk countries, whereas countries below that threshold are regarded as medium or low risk countries. If we want to compare cost of debt for both sub-groups of countries over time, year effects should be considered. The Asian crisis in 1997 and the Global Financial Crisis did have an impact on cost of debt, and they affected developing and developed countries differently due to loose monetary and fiscal policies in some countries. To account for these year effects, we ran a regression to explain cost of debt with year dummies. The year dummies alone only explain 0.45% of the observed variability in cost of debt. Yet, the F-test with a test statistic of 32.15 and p-value of 0.000 indicates explanatory power. Fig. 1 plots year adjusted average cost of debt in low and high-risk countries. After accounting for year effects, unexplained cost of debt has remained on a higher level in high-risk countries throughout the investigation period.

Table 1 reports cost of debt (COD), financial leverage (LEV), working capital relative to total assets (WC) and interest coverage (COVER) for low and high-risk countries in terms of their climate vulnerability. In line with Figure 1, cost of debt is considerably higher in countries more exposed to climate risk with a median of 6.1% compared to 3.2%. Companies located in these countries have higher financial leverage and working capital, although the difference in financial leverage is modest with a median of 12.7% compared to 12.2%. Median interest coverage is 4.38 in high-risk countries, which is considered healthy by rating agencies. However, companies in low-risk countries exhibit a median in excess of 8. Descriptive evidence suggests that companies in countries with more exposure to climate risks exhibit higher indebtedness

[2] We also considered alternative measures based on taking the average level of debt in year t and t − 1, which does not lead to qualitatively different results.

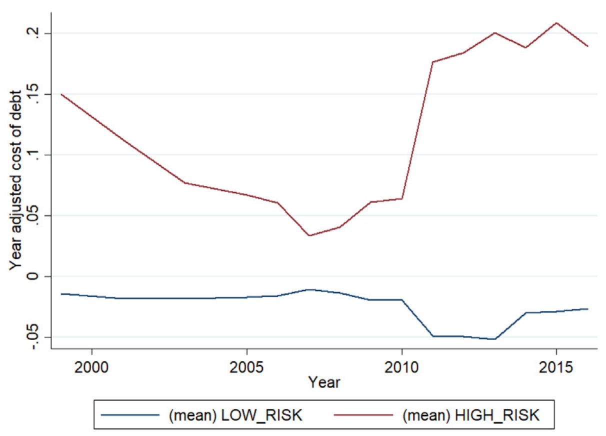


Fig. 1. Year adjusted average cost of debt in low and high-risk countries Notes: We explain cost of debt using year dummies and predict residuals. The average unexplained cost of debt is plotted for the two sub-groups of countries.

and higher financing costs. In addition, interest coverage suggests that financial risk is higher, which might justify higher cost of debt.

Table 2 shows descriptive statistics including the number of observations (N), the mean, median (p50), standard deviation (sd), the minimum, the maximum, the 25-percentile and the 75-percentile for the whole sample. The dependent variables refer to cost of debt (COD) measured based on interest expenses and short and long-term debt, the components of cost of debt (FIRM COMP, COUNTRY COMP, LONGRUN COMP) and cost of equity (COE). To obtain measures of cost of equity two approaches are followed. First, dividends relative to the value of equity are used to obtain firm-level measures (COED). Second, country-level measures refer to the country beta (BETA), i.e. the empirical beta coefficient of the countries' leading stock market index in relation to the US stock market index, and the market risk premium (MRP). The dividend-based measure is of limited use for certain industries, such as high-tech. Hence, the study focuses on the second approach.

Climate vulnerability is denoted VUL and based on the ND-GAIN. The following firm-level controls are expressed relative to

Table 1
Cost of debt and financial variables in low and high-risk countries.

Variables	N	Mean	Sd	Min	p25	Median	p75	Max
Low-risk countries								
COD	76,606	0.165	0.356	0.015	0.032	0.057	0.107	1.894
LEV	76,606	0.153	0.131	0.000	0.041	0.122	0.235	0.474
WC	76,606	0.167	0.192	−0.408	0.030	0.154	0.291	0.701
COVER	76,606	42.755	106.838	0.442	2.874	8.317	26.626	612.85
High-risk countries								
COD	18,431	0.309	0.492	0.015	0.061	0.111	0.26	1.894
LEV	18,431	0.166	0.146	0.000	0.037	0.128	0.268	0.474
WC	18,431	0.195	0.201	−0.408	0.053	0.179	0.325	0.701
COVER	18,431	33.721	101.13	0.442	1.471	4.381	14.625	612.85

Notes: After listwise deletion, two sub-samples of countries are defined based on whether they belong to the top 25% in terms of climate vulnerability or otherwise. The former sub-group is labelled high-risk countries. Descriptive statistics for both sub-groups include the number of observations (N), means, standard deviations (Sd), minimums (Min), 25th percentile (p25), medians, 75th percentile (p75), and maximums (Max).

Table 2
Descriptive statistics.

Variable	N	Mean	Sd	Min	p25	Median	p75	Max
COD	101,532	0.19	0.39	0.01	0.03	0.06	0.13	1.89
COE	96,733	0.04	0.02	0.00	0.03	0.04	0.05	0.10
COED	101,528	0.10	10.50	−94.38	0.00	0.02	0.05	3096.43
BETA	99,707	0.60	0.28	−0.57	0.42	0.55	0.84	1.66
MRP	98,507	0.07	0.03	0.05	0.06	0.06	0.09	0.23
VUL	101,532	0.37	0.06	0.26	0.34	0.37	0.37	0.57
N VUL	101,532	0.45	0.07	0.28	0.41	0.46	0.51	0.55
M RAIN	95,037	103.32	52.70	1.53	57.03	97.87	142.18	311.04
SD RAIN	95,037	53.10	31.94	2.67	22.98	56.00	73.05	314.91
M TEMP	95,037	13.78	7.50	−6.48	9.04	11.42	20.90	28.96
SD TEMP	95,037	6.81	2.93	0.22	4.55	8.05	9.14	15.89
LEV	101,532	0.16	0.13	0.00	0.04	0.12	0.24	0.47
WC	101,532	0.17	0.19	−0.41	0.03	0.16	0.30	0.70
COVER	101,532	42.31	108.00	0.44	2.57	7.61	25.07	612.85
SIZE	101,532	19.74	1.94	13.73	18.36	19.71	21.21	22.93
DIV	101,532	0.01	0.02	0.00	0.00	0.01	0.02	0.06
TANG	101,532	0.31	0.22	0.00	0.12	0.27	0.45	0.81
ROA	101,532	0.07	0.05	0.00	0.03	0.06	0.10	0.20
IND RISK	101,532	0.17	0.37	0.00	0.00	0.00	0.00	1.00
VOL	101,532	560.04	1143.69	0.31	9.15	49.2	375.81	4508.17
GDP	101,532	10.03	1.25	6.45	9.39	10.7	10.77	11.63
GROWTH	101,532	1.83	2.52	−14.38	0.8	1.58	2.97	23.94
POP	101,532	328.07	866.26	1.72	51.6	253.47	350.54	7915.73
LAW	101,532	1.08	0.72	−1.85	0.52	1.34	1.6	2.1

Notes: Descriptive statistics include the number of observations (N), means, standard deviations (Sd), minimums (Min), 25th percentile (p25), medians, 75th percentile (p75), and maximums (Max).

total assets. They include financial leverage (LEV), net operating working capital (WC), interest coverage (COVER), cash holding (CASH), dividend payments (DIV), research and development (RD), tangible assets (TANG) and return on assets (ROA). Finally, to account for firm size we use the log of total assets (SIZE).

Country-level controls refer to the log of GDP per capita in constant 2010 USD (GDP), annual GDP per capita growth rate (GROWTH), population density (POP), and the rule of law (LAW). Industry measures account for cash flow risk in the industry (VOL) and flag high-risk industries (IND RISK) such as oil, gas, energy and agriculture.

5.2. Endogeneity

Trying to explain cost of debt using climate vulnerability and a set of explanatory variables including macroeconomic controls might suffer from endogeneity depending on how climate vulnerability is measured. A stated in Section 4.2, we use climate vulnerability (VUL) compiled by the Notre-Dame Global Adaptation Initiative (ND-GAIN). ND-GAIN also reports a readiness index, which combines many economic indicators, increasing the likelihood of endogeneity problems. However, even the climate vulnerability index contains some measures, which are potentially correlated with macroeconomic variables. Table 3 outlines the underlying measures used in the construction of the climate vulnerability index in the six life-supporting sectors (e.g. water, food, etc.).

To disentangling climate and economic measures in the climate vulnerability index, we explore the underlying raw data used to construct the climate vulnerability index and remove measures that exhibit a strong relation with macroeconomic variables. Table 3 indicates whether the respective measure has a low, medium or high alleged correlation with economic variables. From raw data, we re-construct a vulnerability index, which excludes measures with assumed high correlation with economic variables. Hence, we take indicators 1, 2 and 3 for the food sector, indicators 1, 2, 3 and 4 for water, 1 and 2 for health, 1, 2, 4, 5 and 6 for ecosystems, 1 and 2 for human habitat, and 1, 2, 3 and 4 for infrastructure. This newly constructed index denoted N_VUL reflects countries' climate vulnerability but should be less correlated with countries' financial or economic conditions, which might cause endogeneity.

To test for endogeneity in our panel dataset, we follow Wooldridge (2010). Starting with a random-effects model on the firm level, we try to explain cost of debt (COD) using the original climate vulnerability index (VUL) and a set of control variables including financial leverage (LEV), working capital (WC), interest coverage (COVER), firm size (SIZE), dividend payments (DIV), tangible assets (TANG) and return on assets (ROA).

$$COD_{it} = \alpha_1 + \beta_1 VUL_{jt} + \beta_2 SIZE_{it} + \cdots + u_i + \varepsilon_{it} \quad (4)$$

In Eq. (4), u_i refers to the firm-level random effect, capturing any unobserved firm-level variables. A second equation explains the alleged endogenous variable, the climate vulnerability index (VUL), using all explanatory variables in (4) and the newly constructed vulnerability index denoted N_VUL.

$$VUL_{jt} = \alpha_2 + \delta_1 N\_VUL_{jt} + \beta\delta_2 SIZE_{it} + \cdots + w_{it} \quad (5)$$

From Eq. (5) (see [R1] in Table 4), we obtain the residuals, which we include in the first Eq. (4). The coefficient of the residual denoted VUL_hat exhibits a p-value of 0.000. Hence, we reject the null hypothesis that the coefficient is equal to zero, suggesting that the climate vulnerability index (VUL) is endogenous (see [R2] Table 4).

Accordingly, an instrumental variable approach is needed; however, we must ensure that the newly constructed climate vulnerability index (N_VUL) is a suitable instrument. Considering GDP per capita as a proxy for countries' economic and financial conditions, the original climate vulnerability index exhibits a very high negative correlation (−0.8676). This is in line with our finding that the climate vulnerability index (VUL) is endogenous as countries with low GDP per capita, i.e. challenging economic and financial conditions, tend to score highly in terms of climate vulnerability. The newly constructed climate vulnerability index (N_VUL) is positively correlated with the climate vulnerability index (VUL) with a correlation coefficient of (0.7207) and – most importantly – shows a much lower negative correlation of −0.3331 with GDP per capita. These findings hint that the newly constructed index might be a suitable instrument.

However, to ensure that the newly constructed index passes an endogeneity test, additional instruments are needed. Using country-level data provided by the World Bank on monthly temperature and rainfall from 1991 to 2016, we determine annual average temperature and rainfall (M_RAIN, M_TEMP) as well as

Table 3
Measures for climate vulnerability and their relatedness to economic variables.

Sector	Indicators	Related to economic variables
Food	1 Projected change of cereal yields	Low
	2 Projected population change	Medium
	3 Food import dependency	Medium
	4 Rural population	High
	5 Agriculture capacity	High
	6 Child malnutrition	High
Water	1 Projected change of annual runoff	Low
	2 Projected change of annual groundwater recharge	Low
	3 Fresh water withdrawal rate	Low
	4 Water dependency ratio	Low
	5 Dam capacity	High
	6 Access to reliable drinking water	High
Health	1 Projected change of deaths from climate induced diseases	Medium
	2 Projected change in vector-borne diseases	Medium
	3 Dependency on external resource for health services	High
	4 Slum population	High
	5 Medical staff	High
	6 Access to improved sanitation facilities	High
Ecosystems	1 Projected change of biome distribution	Low
	2 Projected change of marine biodiversity	Low
	3 Natural capital dependency	High
	4 Ecological footprint	Medium
	5 Protected biome	Medium
	6 Engagement in international environmental conventions	Medium
Habitat	1 Projected change of warm periods	Low
	2 Projected change of flood hazard	Low
	3 Urban concentration	High
	4 Age dependency ratio	High
	5 Quality of trade and transport infrastructure	High
	6 Paved roads	High
Infrastructure	1 Projected change of hydropower generation capacity	Medium
	2 Projected change of sea level rise impacts	Medium
	3 Dependency on imported energy	Medium
	4 Population living under 5 m above sea level	Medium
	5 Electricity access	High
	6 Disaster preparedness	High

Table 4
Endogeneity tests.

	[R1]	[R2]	[R3]	[R4]
VUL		−0.568***		
VUL_hat		2.233***		
N_VUL	0.658***			−0.306***
N_VUL_hat				0.022
LEV		−1.315***		−1.299***
WC	0.012***	−0.100***	0.006***	−0.119***
COVER	−0.000***	−0.000***	0.000***	−0.000***
SIZE	−0.006***	−0.034***	0.001***	−0.029***
DIV	0.324***	0.774***	−0.245***	0.244
TANG	0.033***	−0.049***	0.005***	−0.087***
ROA	0.083***	0.192***	0.018***	0.018
M_RAIN			0.000***	
SD_RAIN			0.001***	
M_TEMP			0.009***	
SD_TEMP			0.024***	
Adj. R^2	0.581		0.794	
R^2_w		0.121		0.123
R^2_b		0.261		0.218
R^2_o		0.197		0.164
N	101,532	101,532	95,037	95,037

Note: [R2] and [R4] refer to firm-level random effects with clustered standard errors. [R1] and [R2] are OLS regression to predict climate vulnerability (VUL) and the newly constructed index (N_VUL), respectively. VUL_hat and N_VUL_hat refer to residuals from equations [R1] and [R2], respectively. For random effects models, overall (o), within (w) and between (b) R-squared are reported.
* p < 0.05.
** p < 0.01.
*** p < 0.001.

standard deviations of temperature and rainfall (SD_RAIN, SD_TEMP). The four exogenous variables, i.e. not affected by country-level economic variables, are used in equation (5) and explain 79.4% of the observed variability of N_VUL (see [R3] in Table 4). Inserting the predicted residual from this equation into the first equation leads to an insignificant coefficient of N_VUL_hat, suggesting that the newly constructed index is indeed exogenous and is a suitable instrument (see [R4] in Table 4).

Having found a valid instrument, we adopt an instrumental variables panel-data model, where our constructed climate vulnerability index serves as an instrument for the 'off the shelf' climate vulnerability index. Firm-level effects are modelled using random effects, and our models include country and year dummies to capture any unobserved year effects or country-specific effects.

5.3. The determinants of cost of debt

Selecting cost of debt as dependent variable, five multivariate models provide insights into the impact of climate vulnerability (VUL) on firms' cost of debt. Table 5 presents the five model specifications. In line with Section 5.2, all models refer to instrumental variable regressions, where the newly constructed climate vulnerability index (N_VUL) serves as an instrument for the ND-GAIN climate vulnerability index (VUL). To account for unobserved country-level and year effects, all specifications add country and year dummies. As we work with panel data, i.e. firms observed over time, all models also consider firm-level random effects. Hence, we can be confident that any remaining partial impact of climate vulnerability is not explained by unobserved firm, country or year effects or affected by an endogeneity bias due to the construction of the ND-GAIN climate vulnerability index.

Specification [A1] demonstrates that climate vulnerability as a single factor increases firms' cost of debt. Model [A2] incorporates firm controls, highlighting expected partial impacts such as negative effects of firm size (SIZE), working capital (WC), interest coverage (COVER) and tangible assets (TANG). Specification [A3] adds industry measures and demonstrates that firms in industries with more pronounced cash flow volatility (VOL) do exhibit higher cost of debt, while other partial impacts remain unchanged. Operating in a high-risk industry such as such as oil, gas, energy and agriculture (IND RISK) does not seem to add explanatory power.

Adding country-level controls in model [A4] changes the sign of climate vulnerability but no other partial effects. Hence, even after accounting for endogeneity of the ND-GAIN climate vulnerability index some problems remain as the rule of law and GDP per capita are highly correlated with a correlation coefficient of 0.882. Finally, model [A5] adds financial leverage (LEV), which is associated with higher cost of debt, which seems to be counter intuitive. However, if firms face high cost of debt, they might be forced to look for alternative sources of finance, reducing their financial leverage. This effect might also explain that high dividend payments (DIV) are associated with high cost of debt, which can be used as a proxy for cost of equity. Firms with higher profitability (ROA) seem to face higher cost of debt. In countries with expensive access to debt, internal finance is the predominant source of funding, explaining the positive association between cost of debt and ROA.

To disentangle the impact of climate vulnerability on cost of debt and the alleged impact on access to finance, which might drive our findings regarding the negative impact of financial leverage on cost of debt, Section 5.5 specifies structural equation models (SMEs). In these models, we can also account for the fact that countries with low GDP per capita tend to also exhibit weak governance.

5.4. Cost of equity

Establishing the impact of climate vulnerability on cost of equity is more challenging as firm level proxies of cost of equity are more difficult to obtain. There are two approaches to estimating cost of equity. First, one could rely on a dividend growth model and use dividends relative to the value of equity as a proxy. Our measure denoted COED refers to this approach. However, many firms, mostly in the high technology sector, do not pay any dividends, limiting the usefulness of this measure. Second, the capital asset pricing model (CAPM) suggests that cost of equity of a firm i can be estimated using a stochastic market model as in (5), where r_{mt} represents the market index and r_{ft} is the risk-free rate.

Table 5
Determinants of cost of debt.

	[A1]	[A2]	[A3]	[A4]	[A5]
VUL	4.360***	3.270**	3.295**	0.643	−0.201
WC		−0.185***	−0.185***	−0.142***	−0.112***
COVER		−0.000***	−0.000***	−0.000***	−0.000***
SIZE		−0.035***	−0.034***	−0.039***	−0.019***
DIV		0.653***	0.653***	0.654***	0.119
TANG		−0.295***	−0.293***	−0.269***	−0.134***
ROA		0.365***	0.366***	0.359***	−0.033
IND_RISK			−0.009	−0.006	−0.004
VOL			0.000***	0.000***	0.000
GDP				0.422***	0.103**
GROWTH				−0.004***	−0.002*
POP				−0.000***	−0.000**
LAW				−0.058***	−0.023
LEV					−1.278***
R^2_w	0.058	0.095	0.095	0.106	0.216
R^2_b	0.092	0.152	0.153	0.161	0.295
R^2_o	0.000	0.012	0.012	0.025	0.125
N	101,532	101,532	101,532	101,532	101,532

Note: All models refer to instrumental variable regressions, where the newly constructed climate vulnerability index (N_VUL) serves as an instrument for the ND-GAIN climate vulnerability index (VUL). All specifications add country and year dummies. All models use firm-level random effects. Overall (o), within (w) and between (b) R-squared are reported.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

$$r_E = r_f + \beta(Er_m - r_f) \qquad (6)$$

Eq. (6) is difficult to estimate in less developed markets as these economies tend to be less integrated, resulting in lower betas. Moreover, betas tend to vary over time, and the quality of data (e.g. lack of trading) is an issue. Hence, we estimate country-betas, comparing the leading stock market index with the US market, i.e. we take the perspective of an US investor. The difference between countries' leading stock market index and the risk-free rate is the market risk premium (MRP).

Table 6 shows multivariate models that explain country-level measures such as the expected cost of equity (COE) using country betas and countries' market-risk premium in column [B1], whereas specification [B2] explains country betas and [B3] countries' market risk premia. All models refer to instrumental variable regressions, where the newly constructed climate vulnerability index (N_VUL) serves as an instrument for the ND-GAIN climate vulnerability index (VUL). Specifications [B1] to [B3] are country-level models, which include year dummies.

As shown in specification [B1], overall climate vulnerability does not have a significant partial impact on countries' cost of equity. Models [B2] and [B3] show that climate vulnerability reduces a country's beta, whereas it increases a country's market

Table 6
Determinants of cost of equity.

	[B1]	[B2]	[B3]	[B4]
VUL	0.022	−2.025***	0.125***	−6.312
BETA	0.074***			
MRP	0.303***			
LEV				0.533
WC				0.101
COVER				0.000
SIZE				0.019
TANG				0.296
ROA				−0.122
IND_RISK				0.189*
VOL				−0.000
GDP	0.002**			0.111
GROWTH	0.000			0.011
POP	−0.000			−0.000
LAW	−0.002***			0.286
Adj. R^2	0.885	0.324	0.194	
R^2_w				0.001
R^2_b				0.007
R^2_o				0.000
N	762	797	934	101,528

Note: All models refer to instrumental variable regressions, where the newly constructed climate vulnerability index (N_VUL) serves as an instrument for the ND-GAIN climate vulnerability index (VUL). Specifications [B1] to [B3] refer to country-level models. Year dummies are added in these three models. Model [B4] uses firm-level random effects and adds country and year dummies. All specifications add country and year dummies. For random effects models, overall (o), within (w) and between (b) R-squared are reported.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

risk premium. Countries more exposed to climate risk tend to be less developed and hence less integrated with developed markets such as the US, reducing the correlation between markets, captured by the country beta. In contrast, the market risk premium – both effects seem to offset each other. Using our firm-level proxy of cost of equity, model [B4] applies firm-level random effects and adds country and year dummies. Model [B4] cannot establish any partial impact on firm-level proxies using dividend payments. In summary, there is limited evidence that climate vulnerability contributes to higher cost of equity.

5.5. Structural equation model

The instrumental variable approach used to derive the findings in Tables 5 and 6 did account for the endogeneity of the ND-GAIN climate vulnerability index. However, two additional issues remain: first, GDP per capita and the rule of law are highly correlated; second, access to finance might be constrained in countries more exposed to climate risk. The latter might explain our findings based on model [A5] in Table 5 that firms with higher leverage exhibit lower cost of debt, which is counter intuitive.

To disentangle the effect of climate vulnerability and its alleged association with cost of debt and access to finance, we specify a structural equation model. Fig. 2 illustrates a simplified structure of the model, which permits that climate vulnerability affects cost of debt directly and indirectly through its impact on access to finance, i.e. firms positioned in countries with high climate vulnerability might not get the level of debt needed. Hence, these financially constrained firms exhibit low leverage and high working capital as other sources of funding are used such as trade credit.

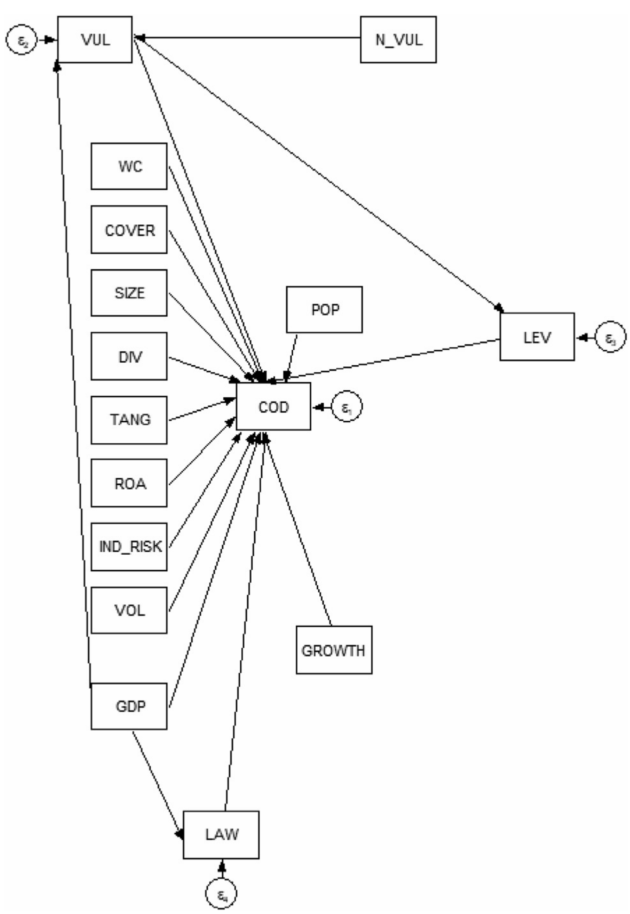


Fig. 2. Illustrated structural equation model *Notes:* We estimate four equations: (1) explaining cost of debt (COD) with a set of explanatory variables including leverage (LEV) and climate vulnerability (VUL); (2) explaining the rule of law (LAW) using GDP per capita; (3) explaining climate vulnerability (VUL) using the newly constructed index (N_VUL) and GDP; (4) explaining access to finance (LEV) using climate vulnerability and other variables.

To derive a model with good fit, we start with a parsimonious specification and add neglected links or error covariances into the model as suggested by modification indices. The initial specification takes model [A5] to explain cost of debt (COD). It then adds additional equations to capture the link between countries' GDP per capita and the rule of law and – similar to our instrumental variable approach – the impact of GDP per capita and the newly constructed climate vulnerability index on the ND-GAIN climate vulnerability index. Finally, a fourth equation models financial leverage, as a measure of access to debt finance, using climate vulnerability, firm-level and macroeconomic variables as controls. This initial model exhibits inadequate goodness-of-fit measures as the Root Mean Square Error of Approximation (RMSEA) is 0.108, above the cut-off point of 0.1, and the Comparative Fit Index CFI is 0.944, slightly below 0.95 suggested by Acock (2013). Hence, in line with Wooldridge (2010) and Sörbom (1989), we determine modification indices and incorporate additional variables (one-by-one) and covariances between error terms until we obtain a model that satisfies these criteria. Finally, we add country and year-dummies to capture any unobserved variables.

Climate vulnerability (VUL) has a positive direct effect on cost of debt shown in column one [C1] of Table 7 in line with previous models [A1] to [A4]. In addition, column three [C3] shows that companies based in countries with high climate vulnerability exhibit lower financial leverage. That is, after controlling for firm-level variables (firm size, interest coverage, dividend payments, tangible assets, return on assets) and macroeconomic variables (GDP, growth, population growth, rule of law), these firms do not take or get the same expected level of debt. Hence, climate vulnerability has an indirect effect through restricting access to finance. Column two [C2] reiterates our finding that the ND-GAIN climate vulnerability index is correlated with GDP per capita and the newly constructed climate vulnerability index (N_VUL). Finally, column four [C4] shows the interrelation between GDP per capita and the rule of law. The effect of the rule of law is more complicated, as the direct effect on cost of debt is negative [C1] – but firms located in countries with better governance can achieve higher financial leverage, providing a positive indirect effect of the rule of law.

Are the direct and indirect effects of climate vulnerability on cost of debt of economic significance? On average, climate vulnerability has increased by 0.0057 from 1991 to 2017, which resulted in a direct effect of $0.0057 \times 1.102 = 0.0063$, i.e. on average cost of debt has increased by 0.63%. In addition, the indirect effect through climate vulnerability's impact on financial leverage has contributed to $0.0057 \times (-0.071) \times (-1.116) = 0.0005$. Hence, the combined impact on cost of debt has been 0.63% + 0.05% = 0.68%.

6. Conclusion

Our article combines the effect of climate vulnerability on firms' cost of capital as well as financial exclusion of firms. Our analysis highlights a previously under-appreciated economic cost of climate change for climate vulnerable developing economies. Our results suggest that companies in countries with a greater exposure to climate risks exhibit higher financing costs and are financially more constrained.

This has significant implications for economic development: higher corporate financing cost and financial exclusion restrain economic growth and development, reduce tax revenue, and limit the scope of governments to undertake investments in public

Table 7
Structural equation model.

Dependent variable	[C1] COD	[C2] VUL	[C3] LEV	[C4] LAW
VUL	1.102**	–	−0.071***	–
N_VUL		0.426***	–	–
LEV	−1.116***	–	–	–
WC	−0.103***	–	–	–
COVER	−0.000***	–	−0.000***	–
SIZE	−0.016***	–	0.016***	–
DIV	0.145	–	−0.054*	–
TANG	−0.136***	–	0.099***	–
ROA	−0.048	–	−0.235***	–
IND_RISK	−0.006	–	–	–
VOL	0.000	–	–	–
GDP	0.179***	−0.036***	−0.043***	0.506***
GROWTH	−0.002*	–	0.001***	–
POP	−0.000***	0.000***	−0.000***	–
LAW	−0.039**	–	0.065***	–
RMSEA	0.085			
CFI	0.966			
N	101,532			

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

infrastructure and climate adaptation. This, in turn, contributes to greater vulnerability, curbs economies' growth prospects and puts the corporate sector in climate vulnerable developing economies at a disadvantage when competing in both domestic and foreign markets. Thus, the climate vulnerability risk premium could cause a vicious circle, where a higher cost of capital reduces both public and private sector investment, suppresses firms' growth and public tax revenue, and limits the scope for public adaptation finance.

Given that climate risks are expected to increase in the future, climate vulnerability is likely to increase without adaptation investments that can mitigate these risks, which implies that the cost of capital for the public and private sector in climate vulnerable economies are bound to increase unless this vicious circle can be reversed. For this to happen, climate vulnerable developing economies – which have not caused global warming and are not able to address the root causes through national action – will need international support. International support through innovative risk transfer mechanisms would help to reduce the cost of capital in climate vulnerable countries, enabling private and public investments that will empower these countries to enter a virtuous circle where higher investments and growth allow for greater adaptation finance, greater resilience and lower climate vulnerability, which will reduce the cost of capital, facilitate further investment, and improve firm competitiveness.

Conflict of interest statement

The authors have no financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

Declarations of interest

None.

Acknowledgements

We are grateful for financial support provided by the UK's Economic and Social Research Council (ESRC) and the National Natural Science Foundation of China (NSFC) under the Newton Fund for the research project 'Developing financial systems to support sustainable growth in China – The role of innovation, diversity and financial regulation' (ESRC: ES/P005241/1, NSFC: 71661137002). In addition, this research was supported by the National Social Science Fund of China (Project Number: 17ZDA071). Sibel Ayas' research visit at SOAS University of London was supported by the Research Fellowship Programme funded by the Turkish Government.

Appendix. Definitions of variables and data sources

Variable	Definition	Data source
COD	Cost of debt measured as interest expense in year t divided by total debt reported in period t	Thomson Reuters Eikon database
COE	Country-level cost of equity estimated using country betas and market risk premiums	Damodaran (2013)
COED	Firm-level cost of equity measured as dividend payments relative to equity	Thomson Reuters Eikon database
BETA	Country betas are estimated using each countries' leading stock market index regressed on the return of the US stock market	Thomson Reuters Eikon database
MRP	Market risk premium defined as average stock market return minus the risk-free rate proxied by 10-year US government bond yield	Damodaran (2013)

Appendix (*continued*)

Variable	Definition	Data source
VUL	ND-GAIN climate vulnerability index	ND-GAIN
N VUL	Newly constructed climate vulnerability index (see Section 5.2)	ND-GAIN (raw data)
M RAIN	Annual average rainfall based on monthly data	World Bank
SD RAIN	Annual standard deviation of rainfall based on monthly data	World Bank
M TEMP	Annual average temperature based on monthly data	World Bank
SD TEMP	Annual standard deviation of temperature based on monthly data	World Bank
LEV	Leverage defined as the ratio of a firm's total debt to total assets	Thomson Reuters Eikon database
WC	Working capital refers to operating current assets minus operating current liabilities	Thomson Reuters Eikon database
COVER	Interest coverage refers to earnings before interest and taxes divided by interest expenses	Thomson Reuters Eikon database
SIZE	Firm size is defined as the log of total assets	Thomson Reuters Eikon database
DIV	Dividend payments relative to total assets	Thomson Reuters Eikon database
TANG	Tangible assets relative to total assets	Thomson Reuters Eikon database
ROA	Return on assets	Thomson Reuters Eikon database
IND RISK	Industries most affected by climate risk such as oil, gas, coal, energy & agriculture	Thomson Reuters Eikon database
VOL	Volatility of cash flows to total assets in an industry defined based on two-digit GICS codes	Thomson Reuters Eikon database
GDP	Log of GDP per capita in constant 2010 USD	World Development Indicators
GROWTH	Annual GDP per capita growth rate	World Development Indicators
POP	Population density	World Development Indicators
LAW	The rule of law	World Governance Indicators

References

Acock, A. (2013). *Discovering structural equation modeling using stata*. College Station, TX: STATA Press.

Alano, E., & Lee, M. (2016). *Natural disaster shocks and macroeconomic growth in Asia: Evidence for typhoons and droughts* ADB Working Paper No. 503. Manila: Asian Development Bank.

Beatty, T., & Shimshack, J. (2010). The impact of climate change information: New evidence from the stock market. *The BE Journal of Economic Analysis & Policy, 10*(1), 1–29.

Botzen, W. J. W., Deschenes, O., & Sanders, M. (2019). The economic impacts of natural disasters: A review of models and empirical studies. *Review of Environmental Economics and Policy, 13*(2), 167–188.

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature, 527*(7577), 235–239.

Cavallo, E., Galiani, S., Noy, I., & Pantano, J. (2013). Catastrophic natural disasters and economic growth. *The Review of Economics and Statistics, 95*(5), 1549–1561.

Chava, S. (2014). Environmental externalities and cost of capital. *Management Science, 60*(9), 2223–2247.

Chen, C., Noble, I., Hellmann, J., Coffee, J., Murillo, M., & Chawla, N. (2015). *University of Notre Dame global adaptation index* Country Index Technical Report. Notre Dame, IN: University of Notre Dame.

Damodaran, A. (2013). Equity risk premiums (ERP): Determinants, estimation and implications–the 2012 edition. In O. Roggi & E. I. Altman (Eds.), *Managing and measuring risk: Emerging global standards and regulations after the financial crisis* (pp. 343–455). Singapore: World Scientific.

Dell, M., Jones, B., & Olken, B. (2014). What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature, 52*(3), 740–798.

Dhaliwal, D. S., Li, O. Z., Tsang, A., & Yang, Y. G. (2011). Voluntary nonfinancial disclosure and the cost of equity capital: The initiation of corporate social responsibility reporting. *The Accounting Review, 86*(1), 59–100.

El Ghoul, S., Guedhami, O., Kwok, C., & Mishra, D. (2011). Does corporate social responsibility affect the cost of capital? *Journal of Banking & Finance, 35*(9), 2388–2406.

Felbermayr, G., & Gröschl, J. (2014). Naturally negative: The growth effects of natural disasters. *Journal of Development Economics, 111*(C), 92–106.

Ferreira, S., & Karali, B. (2015). Do earthquakes shake stock markets?. *PLoS ONE, 10*(7) e0133319.

Huang, H., Kerstein, J., & Wang, C. (2018). The impact of climate risk on firm performance and financing choices: An international comparison. *Journal of International Business Studies, 49*(5), 633–656.

IPCC (2018). Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty. [Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., & Waterfield, T. (eds.)] Geneva: Intergovernmental Panel on Climate Change.

Kahn, M. E., Mohaddes, K., Ng, R. N. C., Pesaran, M. H., Raissi, M., & Yang, J.-C. (2019). *Long-term macroeconomic effects of climate change: A cross-country analysis* NBER Working Paper No. 26167. Cambridge, MA: National Bureau of Economic Research.

Kling, G., Lo, Y., Murinde, V., & Volz, U. (2018). *Climate vulnerability and the cost of debt*. Mimeo, London: SOAS University of London. URL: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3198093.

Kling, G. (2018). A theory of operational cash-holding, endogenous financial constraints, and credit rationing. *European Journal of Finance, 24*(1), 59–75.

Klomp, J., & Valckx, K. (2014). Natural disasters and economic growth: A meta-analysis. *Global Environmental Change, 26*(1), 183–195.

Konar, S., & Cohen, M. (2001). Does the market value environmental performance? *Review of Economics and Statistics, 83*(2), 281–289.

Kompas, T., Pham, V. H., & Che, T. N. (2018). The effects of climate change on GDP by country and the global economic gains from complying with the Paris climate accord. *Earths Future, 6*(8), 1153–1173.

Matsumura, E. M., Prakash, R., & Vera-Munoz, S. C. (2013). Firm-value effects of carbon emissions and carbon disclosures. *The Accounting Review, 89*(2), 695–724.

Mendelsohn, R., Kerry, E., Chonabayashi, S., & Bakkensen, L. (2015). The impact of climate change on global tropical cyclone damage. *Nature Climate Change, 2*(3), 205–209.

Monasterolo, I., Battiston, S., Janetos, A. C., & Zheng, Z. (2018). Vulnerable yet relevant: The two dimensions of climate-related financial disclosure. *Climatic Change, 145*(3), 495–507.

Nordhaus, W. (2006). Geography and macroeconomics: New data and new findings. *Proceedings of the National Academy of Sciences, 103*(10), 3510–3517.

Sharfman, M., & Fernando, C. (2008). Environmental risk management and the cost of capital. *Strategic Management Journal, 29*(6), 569–592.

Sörbom, D. (1989). Model modification. *Psychometrika, 54*(3), 371–384.

Wooldridge, J. (2010). *Econometric analysis of cross section and panel data*. New Haven, CT: MIT Press.