GLOBAL COMMISSION ON ADAPTATION

DISCUSSION PAPER

THE ECONOMICS OF (AND OBSTACLES TO) ALIGNING DEVELOPMENT AND CLIMATE CHANGE ADAPTATION

A World Bank Group contribution to the Global Commission on Adaptation

Executive Summary

Climate change has the potential to affect billions of people; it will jeopardize future development, economic growth, and poverty reduction. The lack of financial resources, as well as multiple nonfinancial obstacles (e.g., market or government failures and uncertainties), often impair the ability to reduce its impact through adaptation. Addressing these obstacles can reduce the cost of adaptation, maximize its benefits, and yield significant economic and development co-benefits, making economies more robust and productive and societies fairer and more prosperous.

Adaptation and development are inextricably linked

Failure to adapt to climate change puts billions of people at risk. Natural disasters alone are already pushing 26 million people a year into poverty, and as many as 4 billion people already live in regions that experience severe water stress for at least part of the year. Climate change and population growth will significantly increase the number of people these events affect and the degree to which it affects them—with devastating consequences for food security and quality of life. Climate change also threatens to exacerbate stresses from biophysical conditions, poor soil, biodiversity losses, and environmental degradation. It could push more than 100 million people into poverty by 2030.

Adaptation can reduce vulnerability to climate risks, accelerate development and poverty alleviation, and improve lives. And development generally increases adaptive capacity—by providing access to basic infrastructure and financial services and arming individuals with the knowledge, skills, and means to take action. Some types of development, however, increase vulnerability to climate change. The conversion of mangroves into shrimp farms or uncontrolled urbanization, for example, increases households' income but leaves coastal communities more vulnerable to floods. To ensure that development builds long-term resilience and reduces vulnerability, climate change considerations need to be mainstreamed into economic and development policies.

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Estimating the resources needed to adapt, and the global benefits of adaptation, is difficult…

Countries, firms, and households alike are already adapting, albeit imperfectly, and they will continue to do so. Estimating the costs and benefits of doing "more" to adapt depends on the reference point used in the assessment—the assumptions about the actions individuals and businesses would take in a business-as-usual scenario. Differences in the reference points largely explain the large range of estimates of the global cost of adaptation.

Using simple assumptions about the costs of making investments more resilient, the annual global cost of adaptation has been estimated at between US$28 billion and more than US$100 billion a year by 2030 and US$70 billion to US$500 billion by 2050. If the entire world were to allocate the same share of GDP that Paris or London devotes to adaptation, the global cost would be about US$180 billion a year. Another way to estimate the global cost of adaption is to sum the estimates that 50 countries have provided as part of their Nationally Determined Contributions. Assuming that these estimates are consistent with

Purpose of this Paper

This Discussion Paper frames adaptation as a development challenge, reviewing what is known about its costs and benefits and the obstacles that private and public decision-makers face to adapt to climate change. It explores a number of critical questions: How to measure the costs and benefits of adaptation measures? How to prioritize the most significant or efficient measures or policies? How to identify the role of the public sector and the need for public sector investment?

This paper is the contribution of the World Bank Group to the Global Commission on Adaptation. It was prepared by Stephane Hallegatte, with inputs from Carter Brandon, Richard Damania, Yunziyi Lang, John Roome, Julie Rozenberg, and Arame Tall, as well as the Secretariat of the Global Commission on Adaptation. The paper has benefited greatly from the work of the authors of the World Development Report 2014, *Risks and Opportunity: Managing Risk for Development,* and from the chapter "Economics of Adaptation" of the IPCC AR5 (Chambwera et al. 2014;[1] World Bank 2013 [2]).

About GCA Discussion Papers

The Discussion Papers explore some of the key challenges that the Global Commission on Adaptation will address. They contain preliminary research and analysis, and outline potential solutions. They are intended to stimulate timely discussion and to inform ongoing debate on emerging issues. They therefore lay some of the groundwork for the GCA flagship report and its evidence-based narrative about how humanity can continue to progress, despite the impacts of climate change.

These papers reflect the views of the authors and not of the Global Commission on Adaptation or of the Managing Partners to the Commission

Discussion Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues.

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actual needs—a strong assumption given how simple and partial the adaptation components of most Nationally Determined Contributions are—the annual global cost of adaptation would be approximately US$115 billion a year between now and 2030.

Researchers have also tried to estimate the benefits of adaptation. The 2016 World Bank report, Shock Waves: Managing the Impacts of Climate Change on Poverty[3] estimates that a scenario of "rapid, inclusive, and climate-informed" development could bring down the economic losses from climate change by 0.4 percent of global GDP by 2030, reducing the number of people climate change pushes into poverty from more than 100 million to less than 20 million.

… and costs and benefits are not the only factors that affect decisions

How much a society needs to invest in adaptation depends on how much residual risk it is willing to bear. Risk tolerance depends not only on a country's resources and resilience but also on its level of risk aversion and preferences with respect to allocating resources to other uses.

Considerations of equity and fairness also affect how much adaptation investment needs to be made. In financial terms, adaptation investments yield the highest returns in high-density, high-wealth areas, but the most vulnerable populations are often poor and located in low-density areas. In addition, least-cost adaptation options—such as coastal retreat or migration—may be deemed unacceptable for political, psychological, or cultural reasons. The fact that least-cost options may not be realistic or desirable could significantly increase global adaptation needs, compared with existing estimates.

Not all adaptation is costly, however. In fact, in some cases adaptation actually reduces spending needs.

Tackling the obstacles that prevent or inhibit adaptation action should be a priority

Lack of adequate financial resources often constrains successful adaptation. The appropriate response depends on whether the problem is linked to "funding" (the actor that needs to act cannot afford to pay for the action) or to "financing" (the actor could reimburse a loan but cannot access borrowing). When the problem is linked to financing, nonconcessional loans for government and improved financial inclusion and capital market regulations can be sufficient to make adaptation possible. When the issue is funding, adaptation is possible only if a third party (taxpayers or donors) pays for it, and transfers are required (in the form of grants or subsidized loans).

Not all adaptation is costly, however. In fact, in some cases adaptation actually reduces spending needs. Removing distortive subsidies in the agriculture, water, or energy sector, for example, or deciding not to build infrastructure because it is too exposed to risks from climate change can have positive effects on a country's budget.

No-cost or negative-cost options face other barriers and obstacles to implementation that need to be addressed, including the following:

- Market failures (including externalities and moral hazard, imperfect capital markets, and the inability of private firms to capture all of the benefits of the technologies they create).
- Governance and government failures (lack of capacity or coordination failures across agencies; the influence of interest groups; and the fact that most of the benefits of adaptation are in the form of avoided impacts that are largely invisible and for which policymakers rarely get rewarded).
- Lack of information, behavioral biases, and deep uncertainty, which often lead to strong political opposition to any action.

A project or policy that reduces these obstacles is transformational, in the sense that it enables and facilitates further actions, mobilizes and redirects private and public investments, and helps shift development toward a more resilient path. Transformational change lowers the cost of adapting to climate change.

In addition to reducing the impact of climate change, adaptation action can yield significant economic and development co-benefits

Most climate change adaptation has positive spillovers. Climate-change-conscious urban planning would lead to cities that are less congested, more productive, and more livable, for example. Stronger social safety nets, implemented to help people manage increasingly intense droughts, could serve as the backbone of a social protection system that protects people against all kinds of shocks. Infrastructure that is more resilient to climate change and natural hazards would also be more reliable, reducing the cost that frequent power and water outages impose on firms and households. The urgent need to adapt to climate change may be the political trigger that makes it possible to address fundamental issues that need confronting anyway. Doing so can make economies more efficient and productive and societies fairer and more prosperous.

1. Introduction and Recommendations

Climate change will transform the conditions under which ecosystems, economies, and societies operate, making it vital for all to adapt.[4,5] Temperatures will increase everywhere, with the magnitude of the increase larger in some places than in others. Precipitation will also be affected, including the frequency and intensity of rainfall events. These changes will combine to influence water availability, with increase in water scarcity in many places. Storms and tropical cyclones will see their spatial distribution and intensity affected. Sea level rise will make some regions exposed to much more frequent coastal floods, threatening the existence of small islands. Furthermore, responses of ecosystems will affect ecosystem services and agricultural and forestry productivity.

Countries, firms, and households are already adapting, and will continue to do so. Adaptation is not easy to track or measure since it is embedded in an implicit manner in many decisions (from the localization and architecture of a house to the choice of a crop or the dimension of a culvert) and it provides benefits in the form of unobservable avoided impacts. Some adaptation occurs in an explicit manner; for instance, through national adaptation plans or targeted investments for disaster management. Most adaptation, however, occurs without being considered or framed as adaptation; for instance, when households decide to live away from the flood plain, when firms invest in better supply chain management, or when governments revise their construction norms or flood maps. Although much adaptation takes place as an autonomous response of private actors, it also produces public benefits (e.g., equity and fairness, safety) and depends on public goods (e.g., infrastructure service and information provision). Therefore, government and public sector agencies have a key role to play to facilitate, support, and contribute to the adaptation process.

This paper provides three main recommendations:

1. **Define "adaptation" as broadly as possible, as a development challenge linked to the achievement of development objectives in a context of ever-changing and uncertain natural hazards and environmental stresses.** Poor management of natural hazards and environmental stresses is commonplace today, with high costs in terms of slower development and growth, higher and deeper poverty, and lower quality of life. Climate change will magnify these costs, often in a dramatic manner, making it critical and urgent to adapt. In addition, many adaptation actions are particularly attractive because they can deliver large co-benefits—for example, accelerated development and better lives—by improving how we manage all risks and stresses, including those that are not related to climate change. An excessively narrow definition of adaptation would exclude the most effective and transformational actions that deliver benefits beyond avoided climate change impacts.

2. **Focus on "how" to adapt to climate change and concentrate on the poorest countries and communities.** Given that there is little disagreement about the need to reduce the harm from changing climate and environmental conditions, the case for adaptation needs to focus on the "what" and the "how"—concrete opportunities to do more and better, realistic options to align adaptation with other development objectives and manage the uncertainty, and practical solutions to manage the political economy issues and unavoidable trade-offs with other priorities. These questions are particularly difficult in the poorest countries and for the poorest individuals, where immediate development needs are the greatest and resources the scarcest. There will be more action on adaptation when practical and operational solutions to manage these issues and trade-offs are available to local and national decision-makers.

3. **Look beyond financial costs: removing nonfinancial and structural obstacles to climate change adaptation would increase resilience and reduce climate change impacts without always increasing costs.** Many obstacles to action exist at all levels, from the family or small firm to the international community. They include market failure and bad incentives, government failure and lack of accountability, lack of information, behavioral biases, or deep uncertainties, thus making it difficult to operationalize climate change adaptation and increasing the cost of action. Removing these obstacles will not only minimize the economic costs and maximize the benefits of adaptation while ensuring, in particular, that zero- or even negative-cost opportunities are captured; they also will mitigate the risk of maladaptation.

This paper recommends that context-specific adaptation strategies be designed based on the identification of the obstacles that local private and public decision-makers face in adapting to climate change. In doing so, it aims to ensure that the scarce available resources for adaptation deliver the maximum benefit.

2. Adaptation Is a Development Challenge

There is a strong alignment between development objectives and adaptation objectives. Adaptation reduces vulnerability to existing climate risks and can accelerate development. In addition, development in general increases adaptive capacity through enhancements in human and other capital.

2.1 Climate Change Makes It Vital and Urgent to Improve the Management of Natural Hazards and Environmental Stresses

In spite of recent efforts and improvements, the track record of successfully managing natural hazards and environmental stresses is limited. Climate change will magnify the consequences of these limits. While human losses from natural disasters have been decreasing, their economic costs are rapidly increasing over time, and large-scale disasters are occurring regularly.[6,7,8] According to one estimate, natural disasters are pushing 26 million people a year into poverty, on average.[9] The major factor behind the increase in disaster-related economic loss is the increase in exposure to natural hazards, suggesting insufficient risk management policies, or lack of enforcement.[10] Beyond the impact of disasters, there are also severe impacts of environmental degradation and stresses. As many as 4 billion people already live in regions that experience severe water stress for at least part of the year[11] With populations rising, water stresses will increase: regions where population growth will be the highest are already the most water-stressed.[12] Furthermore, over one-third of the rural population in developing countries is located on less

favored agricultural land and areas, which are constrained by biophysical conditions, poor soil or soil degradation, or poor market access.[13,14] In addition, biodiversity losses and environmental degradation threaten ecosystem services and human development.[15,16,17] All of these issues with natural hazards and environmental stresses will be worsened by climate change.[18]

Adaptation and improved management of natural hazards and environmental stressors can contribute to economic growth and poverty reduction. They can contribute to achieving universal access to basic service, for example, by reducing infrastructure repair costs and facilitating the expansion of power, water, and transport networks. They can contribute to poverty reduction by preventing the shocks that keep people in or close to poverty. They also can contribute to well-being and quality of life by reducing the risks that people have to face, and by improving health and the amenities linked to the environment. (See Section 2.2 for a review of existing estimates of the benefits from climate change adaptation.)

2.2 Development That Mainstreams Climate Considerations Can Reduce Vulnerability to Climate Change

Development and adaptation needs are closely intertwined. Adaptation to minimize the impacts of climate change cannot ignore the increasing needs of a growing and richer population with a changing diet. Adaptation needs are magnified by the need to provide food to (perhaps) more than 9 billion people in 2050. Similarly, risk reduction in cities is a different challenge when accounting for the rapid pace of urbanization in many developing countries. It is critical, for instance, to ensure that flood zoning and stricter construction standards do not become an obstacle for poor rural people who move to cities in search of better jobs, higher income, improved health care, and better education for their children.

The actions that would be the most efficient to reduce future vulnerability to climate change are (well-designed) development policies.[19,20,21] This is especially the case because poverty—and the lack of access to basic infrastructure services, financial services, health care, and social protection—is a strong predictor of vulnerability to climate change, and because governments in low-income countries have fewer resources to prevent and respond to shocks and environmental impacts.

Good development—that is, development that is rapid, inclusive, and takes into account climate change—differs from business-as-usual development. There are well-documented instances of activities aimed to reduce poverty or accelerate development that, in fact, have increased vulnerability to climate change (and other natural risks). For example, the conversion of mangrove forests into shrimp farms may generate economic gains but leave coastal communities more vulnerable to coastal hazards such as storm surges. To align development and climate considerations, climate change needs to be mainstreamed in economic and development policies, and adaptation should not be an afterthought. It would not make sense for a country, a firm, or a household to make its economic decisions disregarding climate change, and then to consider what additional "adaptation" investment is needed because the climate is changing.

Good development alone will not be sufficient to address climate change; targeted adaptation actions will still be needed. Pure climate change adaptation measures (i.e., measures that would not be necessary in the absence of climate change) will also be required, such as adapting building norms to new environmental conditions, upgrading coastal defense to respond to rising sea levels, or improving drainage systems to cope with more intense precipitation. These pure adaptation actions, however, make sense only as complements to development: one cannot improve a drainage system that does not exist or upgrade coastal defenses that still need to be built.

3. Estimating the Global Costs and Benefits of Adaptation Is Difficult

Estimates of the costs and benefits of adaptation have attracted a lot of interest. However, methodological challenges and technical issues make these estimates rather partial and uncertain. This section reviews existing assessments and concludes that while estimates vary widely, studies tend to agree on the existence of a large adaptation potential that comes with a significant incremental cost.

3.1 Studies Share Many Gaps and Limits

An assessment of the costs and benefits of adaptation faces many challenges, including issues with the very definition of adaptation. The large range of estimates originates mostly from fundamental questions relating to (1) the definition of "adaptation" and of a relevant reference point (i.e., the description of a world "without adaptation" against which costs and benefits can be estimated); (2) the acceptable level of residual risks and how fairness and equity considerations are included in the analyses; and (3) whether or not studies assume perfect foresight on future climate or realistically account for the uncertainty. The following subsections explore these issues in turn.

3.1.1 DEFINING THE REFERENCE POINT

Defining an "additional" cost of adaptation, or the benefit to adapt, requires, first, to define a reference point. Different studies have made different choices in this regard. Of course, there is no world with no adaptation —all individuals, firms, and governments actively manage natural hazards and environmental trends and stressors. This lack of an easy reference point makes it difficult to define the additional costs and the benefits of adaptation in an objective way. In practice, there are three options to define a reference point and an adaptation strategy (the additional set of actions whose costs and benefits are assessed):

- **The broadest definition of adaptation**, which takes the current situation with all its imperfections as the reference point and includes all measures to reduce future impacts of natural hazards and stressors. These measures include what is often referred to as "no regret" options; that is, options that would be desirable even in the absence of climate change (like improving early warning systems). These no regret options are also described as the reduction of the "adaptation gap"; that is, the fact that the world is not (and never has been) perfectly adapted to climate conditions. This broad definition of adaptation leads to large costs and benefits since, in this case, adaptation includes many actions that can be considered as development actions, such as the provision of infrastructure services to all. As an illustration, consider a coastal town that has no flood protection and is regularly flooded by tropical storms; with this definition, the cost of adaptation will include the full cost of building a coastal protection system able to cope with rising sea levels.
- **The strictest definition of adaptation**, which includes only the actions that are desirable because of climate change, takes as its reference point an idealized scenario in which all current imperfections in how current natural hazards and stressors are managed are corrected, but at the same time ignoring climate change. This definition—consistent with a strict "additionality" principle—leads to the smallest costs and benefits, since it leaves out all no-regret actions that would make sense without climate change. Getting back to the illustrative coastal town, with this definition the cost of adaptation will not include the full cost of a coastal protection system; rather, it will include only the additional cost of making it stronger to cope with sea level rise.
- **An intermediate definition** takes, as a baseline, a business-as-usual scenario in which the management of natural hazards and environmental stresses is progressively improved over time. It considers "adaptation" as a set of additional actions to improve the situation further and make development more resilient and better adapted to future climates. This definition is the most relevant in policy and operational terms, although it is also the most subjective, since different people have different expectations regarding the pace and quality of future development and how the management of natural hazard and environmental stresses will improve over time in a business-as-usual scenario. To apply this definition to our illustrative coastal town, one would need to make an assumption regarding how and when a coastal protection system would be provided for the town in a business-as-usual scenario without climate change, and then define the adaptation cost as the "incremental" cost of building this protection earlier and/or stronger. Crucially, if the town is assumed to remain unable to afford a protection in the reference scenario and climate change makes the risk unbearable, then the adaptation cost is the "full" cost of the protection, not the incremental cost due to climate change.

Using a broad definition of adaptation is more policy relevant and should be preferred; the incremental cost of adaptation in its narrow definition can be misleading. For our coastal town that is not protected against storm surges because it cannot afford (or access financing for) a coastal protection system, knowing that climate change makes the optimal system 5 percent or 10 percent more expensive

Political choices regarding equity, fairness, and distributional impacts also will have a key impact on adaptation investment needs.

is not very useful. Indeed, for this town, preventing the increase in coastal risks due to climate change (possibly to unbearable levels) is possible only if the full cost of the protection system becomes affordable. Furthermore, financial support that would be calibrated, based on the additional cost (the 5 percent or 10 percent), would not increase the ability of this community to adapt, and would not reduce vulnerability and climate change impacts in the absence of a solution to finance the other 90–95 percent of the full protection cost.

3.1.2 DETERMINING A FAIR AND ACCEPTABLE LEVEL OF RESIDUAL RISK

Adaptation cannot remove all natural risks and prevent all impacts and risks of climate change: some residual risks will have to be tolerated and managed.[22,23] How much needs to be invested in adaptation depends on the level of residual risks and impacts that people deem acceptable. Defining an acceptable level of risks and impacts is difficult because of the complexity of some of the issues and because risk aversion (and tolerance to risk) differs widely across countries, communities, and individuals. There is a lot of variability in the level of flood protection that people benefit from.[24,25] Part of this difference is explained by wealth and income, but there is still a large variability when controlling for these factors, suggesting variances in preferences across countries. Such differences, indeed, have been documented across countries and cultures. In addition, within countries and communities, some individuals are more risk averse than others and may prefer a more precautionary approach.[26,27]

Political choices regarding equity, fairness, and distributional impacts also will have a key impact on adaptation investment needs. In pure economic terms, adaptation and risk management will be most efficient in high-density and high-wealth areas.[28] In contrast the most vulnerable populations are often located in low-income and low-density areas. Obviously, choices regarding how to manage trade-offs regarding where to invest in adaptation will have a large impact on how much resources are needed, and on the level of protection that can realistically be provided to the population. This is particularly important for small islands whose existence may be threatened by climate change and sea level rise. Migration has been presented either as an adaptation option (assuming migration is part of the risk management and adaptation toolbox) or as an expression of the limits to adaptation (assuming migration is the solution of last resort).[29] In some coastal areas with low density and little wealth, migration is more economically efficient than hard protection, but may be considered unacceptable for cultural, political, or psychological reasons, increasing the monetary cost of adaptation beyond what can be considered optimal in an economic model.[30,31]

3.1.3 ACCOUNTING FOR CLIMATE CHANGE UNCERTAINTY AND THE CHALLENGES TO PROACTIVE ACTION

Climate change creates a large uncertainty on future local climate conditions, making it more difficult to plan and design long-lived investments and potentially leading to large economic costs. In spite of progress on climate change modeling, the uncertainty on how local climates will change in the future remains large. In some regions, models disagree on the sign of the future change in rainfall, making it difficult to design water-related infrastructure. This problem is particularly acute in sectors such as urban planning and transit, water management, or energy production, since these sectors are highly sensitive to climate conditions and because decisions in these sectors have implications over long time horizons, ranging from decades to centuries. Once a city is built, either with high-density or a major sprawl, its form cannot be changed, and the legacy of urban choices will extend over centuries. The importance of climate uncertainty is illustrated in a study on hydropower investments in Africa, in which the benefits from knowing in advance how local climates will change in Africa are of the same order of magnitude as the impacts of climate change.[32]

Adaptation costs are lower if a proactive strategy is implemented, and much higher if adaptation is reactive. Taking the example of sea level rise and coastal floods, it is obvious that future adaptation costs will be lower if an anticipated adaptation strategy is implemented immediately so that new urban development only occurs in places where flood protection will be inexpensive and easy in the future. If new development occurs in low-lying places that will become increasingly difficult to protect, then future decision-makers are likely to have no choice but to invest huge amount of resources into upgraded protection systems. Current performance of policymakers at anticipating future, uncertain, and invisible risks raise doubts on the ability to implement a perfectly anticipatory approach to adaptation, which implies higher costs than what estimates may suggest.

3.2 Estimates of the Costs and Benefits of Adaptation Vary Widely

Many studies have explored the costs and benefits of various adaptation options, at different scales and with different coverages. This section reviews some of these studies.

3.2.1 THE POTENTIAL AND LIMITS OF ADAPTATION

Different areas, communities, or countries are adapted to different local climates. For instance, data from the United States show that hot areas (e.g., Houston) are less sensitive to high temperatures than colder ones (e.g., Boston); a year with 10 additional 32°C days reduces output per capita by 2.6 percent in counties in the coldest quintile and by 0.5 percent in the warmest quintile. This difference suggests significant scope for long-run adaptation to climate change if, for instance, Boston becomes a little more like Houston.[33]

However, adaptation cannot fully cancel the negative impacts of higher temperature. The fact that even the hottest, well adapted regions of the United States suffer economically meaningful production impacts from extreme heat suggests that climate adaptation faces limits or entails nontrivial costs. Furthermore, the stability of the estimates over time (since the 1960s) suggests that while adaptation during the last half-century has reduced human losses, it has not fundamentally altered the relationship between temperature and income in the United States.[34]

In some sectors, the potential for adaptation appears more limited, at least with current technologies and institutions. Comparing the impact of similar hurricanes in places where such hurricanes are common or rare shows that adaptation to more intense tropical cyclones is technologically feasible and actually takes place, although it has a limited impact: it is likely to reduce the impact of more intense hurricanes by 3 percent only.[35] In agriculture, available data in the United States suggest a limited historical adaptation of seed varieties or management practices to warmer temperatures.[36] In addition, for corn and soy production in the United States, long-run adaptation is found to have mitigated less than about half of the short-run effects of extreme heat exposure on corn yields.[37]

There is also evidence of maladaptation; that is, measures that aim to reduce vulnerability to climate shocks and changes, but instead increase it. The *Unchartered Water* report finds that in most areas, irrigation infrastructure provides a complete buffer against rainfall shocks in these areas.[38] In arid areas as well as in low-income countries, however, large irrigation infrastructure is found to be less effective at buffering agricultural yields against shocks. In fact, there are regions where the presence of irrigation infrastructure accentuates the impact of shocks on agricultural yields, because it leads farmers toward more water-intensive crops that are vulnerable to a greater extent to drought (a typical example of maladaptation).

3.2.2 ESTIMATES OF THE COSTS AND BENEFITS OF ADAPTATION AT THE SECTOR LEVEL

Some sectors have benefited from more in-depth analyses than others. While some sectors and hazards are relatively easy to explore (e.g., coastal adaptation to sea level rise), others are more difficult (e.g., health or tourism), which explains why all estimates of adaptation costs and benefits are considered partial. This discussion paper cannot provide a comprehensive review of published sector-level analyses of the costs and benefits of adaptation options, although in-depth reviews are available elsewhere.[39]

One of the best-covered sectors is flood management for coastal and river floods, but even in this sector, uncertainties on adaptation costs are large. A forthcoming World Bank report on infrastructure investment needs in developing countries finds that coastal

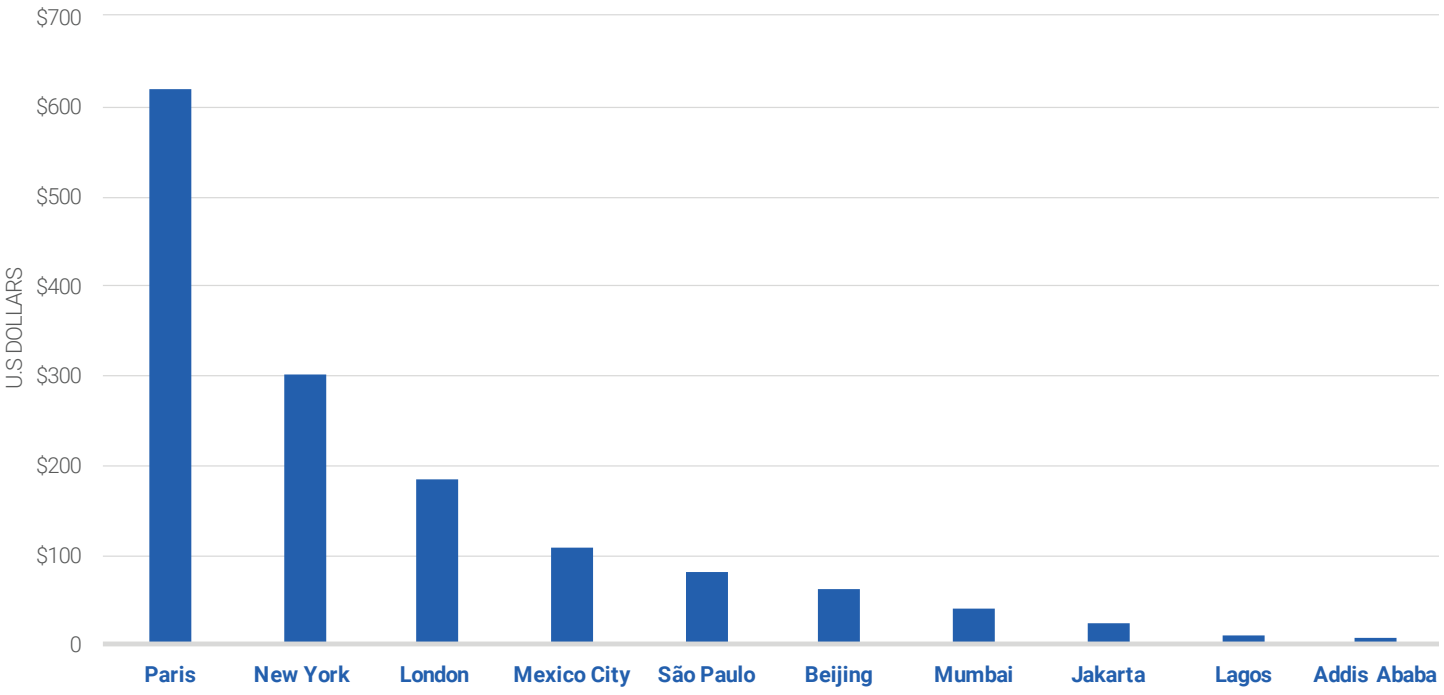
flood protection costs could range between 0.05 percent and 0.20 percent of developing countries' gross domestic product (GDP) a year by 2030, depending on risk tolerance and construction costs. Similarly, river flood protection could cost anywhere between an annual 0.04 percent and 2.4 percent of developing countries' GDP by 2030, depending on risk tolerance and construction costs.

In spite of the uncertainty, flood management is a sector where studies have consistently found a large potential for adaptation, with large benefit-cost ratios. An extreme case is for coastal city and sea level rise: because even a moderate sea level rise can multiply the frequency of coastal floods, it can lead to an increase in average flood losses by multiple orders of magnitude.[40] In such a context, upgrading flood defense has huge benefits, and high benefit-cost ratios. In the 136 largest coastal cities, investments of approximately US$50 billion a year can reduce flood losses from more than US$1trillion to approximately US$60 billion a year (a benefit-cost ratio higher than 15). Generally, river flood management is expected to deliver large benefits, if designed appropriately. Depending on the socioeconomic and climate scenario, global benefits range from US$100 billion to US$800 billion a year for costs between US$30 billion and US$80 billion, with a benefit-cost ratio of between 4 and 10.[41] However, these scenarios include an increase in the level of risk in many places (even when expressed in percent of local wealth).

3.2.3 ESTIMATES OF THE COSTS AND BENEFITS OF ADAPTATION AT THE LOCAL LEVEL

The current "climate change adaptation and resilience" spending in ten megacities, including public and private spending, has also been estimated (Figure 1).[42] In all studied cities, the adaptation economy remains a small part of the overall economy, representing a maximum of 0.33 percent of a city's GDP. Differences in total spending are significant between cities in developed, emerging, and developing countries, ranging from US$23 million in Addis Ababa to US$2.5 billion in New York City. Spending per capita in Paris, New York, and London ranges between US$200 and $600 a year. About one-third of this spending is in the housing sector, another third in infrastructure (i.e., energy, transport, water, communication), and the last third in the rest of the economy (i.e., agriculture, parks, health, among others). As a

FIGURE 1 Annual Per Capita Adaptation Spending in 10 Major Cities, 2014/2015



Source: Georgeson et al. 2016.[43]

simple benchmark, if one were to assume that the absolute spending per capita in Paris or London is what is needed everywhere (i.e., that these cities are taking the problem seriously and acting at the scale that is needed), then the total global adaptation spending need would reach extremely high values, between $1.4 trillion and US$4.2 trillion a year. If the benchmark is done using the spending in proportion to the city GDP, then generalizing the spending ratio in Paris or London to the world would lead to much lower adaptation investment needs, around US$180 billion a year.

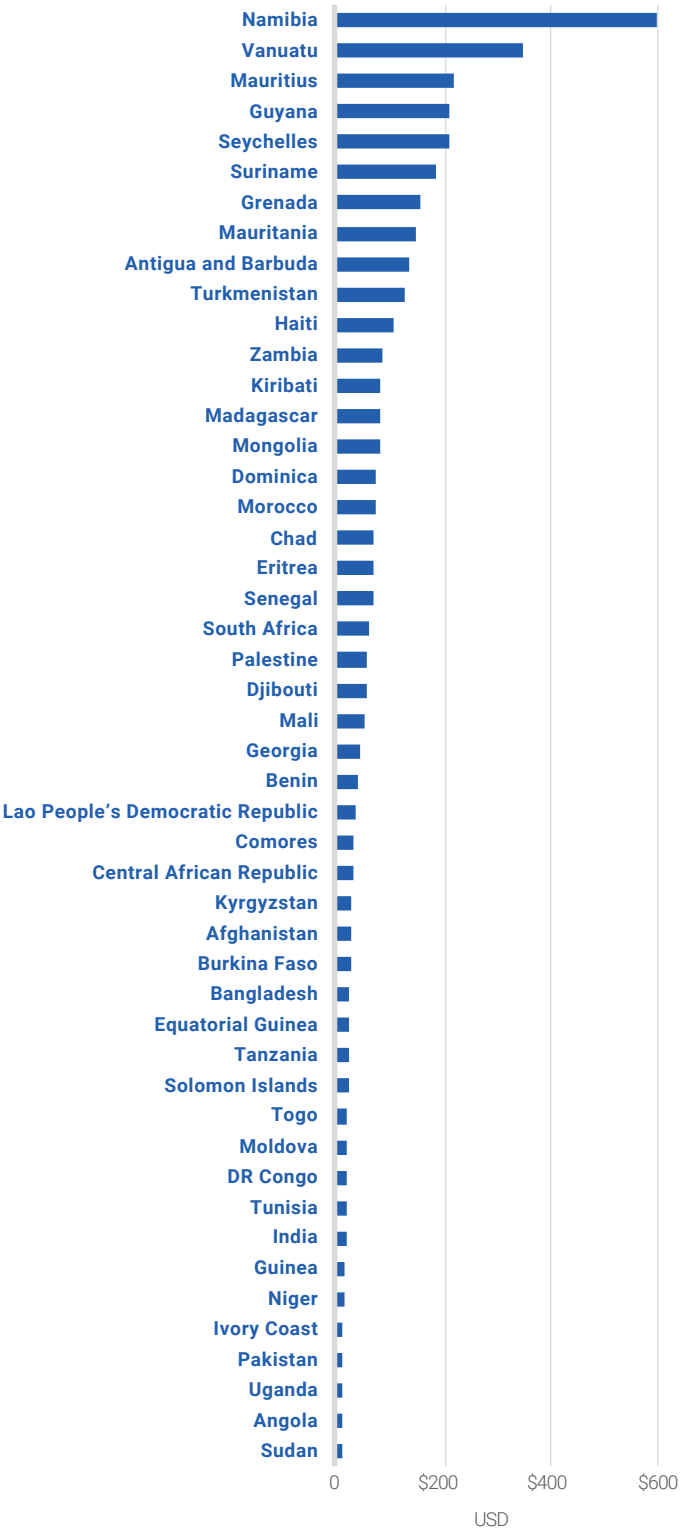
3.2.4 ESTIMATES OF THE COSTS AND BENEFITS OF ADAPTATION AT THE NATIONAL LEVEL

Cost estimates provided in the Nationally Determined Contributions (NDC) of the United Nations Framework Convention on Climate Change offer another, yet limited, point estimation into the cost of adaptation. Fifty countries (totaling 2.4 billion people) have provided an estimate of the cost of the adaptation component of their NDC, with a time horizon going from today to 2050, depending on the country. Here, the estimates provided by countries have been homogenized in terms of "adaptation spending per capita and each year", assuming the totals provided were for a period starting in 2015 and up to the data provided by the NDC (which goes from 2020 to 2050, depending on the country). It is critical to highlight that adaptation components of NDCs are generally poor and, as such, do not form a rigorous basis for estimating national adaptation needs and priorities.

Total adaptation costs in NDCs total US$39 billion a year in the 50 available countries, for an annual cost per capita ranging from US$0.29 (Burundi) to US$594 (Namibia). Figure 2 demonstrates the huge differences across countries, which are due to the process of designing the NDC more than to any difference in vulnerability or adaptation needs. The average cost per capita is US$16 per person a year. Assuming that these estimates are consistent with actual needs—a strong assumption considering how simple and partial most NDCs are, especially in their adaptation component—the global adaptation need would be approximately US$115 billion a year.

Going beyond the available estimates would require the development of national adaptation plans that are more comprehensive (i.e., covering all needs) and granular (i.e., including information at the project level) than what is available today. One in-depth study of Fiji's climate vulnerability and adaptation options provides an example

FIGURE 2 Annual Per Capita Adaptation Cost Estimates in Nationally Determined Contributions



Source: Authors' calculations.

of the development of an adaptation plan, based on the country's development objectives.[44] It analyzes current and future hazards and long-term stresses affecting Fiji, identifying 125 measures in five areas where interventions could minimize current and future impacts of climate shocks and stressors on wellbeing, assets, and development prospects. The total cost of these measures amounts to US$4.5 billion over 10 years, which is close to 100 percent of Fiji's current GDP (and approximately US$500 per capita a year), although they include many actions that are part of the Fiji development plan and are not pure adaptation options.

3.2.5 ESTIMATES OF THE COSTS AND BENEFITS OF ADAPTATION AT THE GLOBAL LEVEL

Multiple studies have explored the global cost of adaptation, using various approaches and methodologies with attempts to aggregate sector-level studies (Table 1). Confidence in these numbers is low since (a) the estimates are derived from only three relatively independent lines of evidence; (b) the choice of reference scenario used to calculate cost is unclear; and (c) simple approaches are used that do not capture the complexity of adaptation.

In a simple modeling of adaptation in two integrated assessment models (DICE and WITCH), adaptation is cost-effective, with benefits that are approximately double of the costs.[47] In an optimal adaptation scenario with no mitigation, the costs of adaptation are 0.28 percent and 0.19 percent of world GDP in the AD-DICE and AD-WITCH models, respectively. The benefits from adaptation are 0.51 percent and 0.38 percent of world GDP, respectively. The net benefits of adaptation are 0.23 percent and 0.20 percent of world GDP in AD-DICE and AD-WITCH (Figure 3). These numbers, however, are to be considered with care as they are based on very simple damage functions.

The *Shock Waves* report[49] also measures the benefit from adaptation, using the broadest possible definition of adaptation. In this case, adaptation is defined as "rapid, inclusive, and climate-informed" development, and therefore include the reduction of the adaptation gap (with universal access to infrastructure services such as water and sanitation) and general development gains (with fewer people relying on low-productivity agriculture, living close to the subsistence level, and spending a large share of

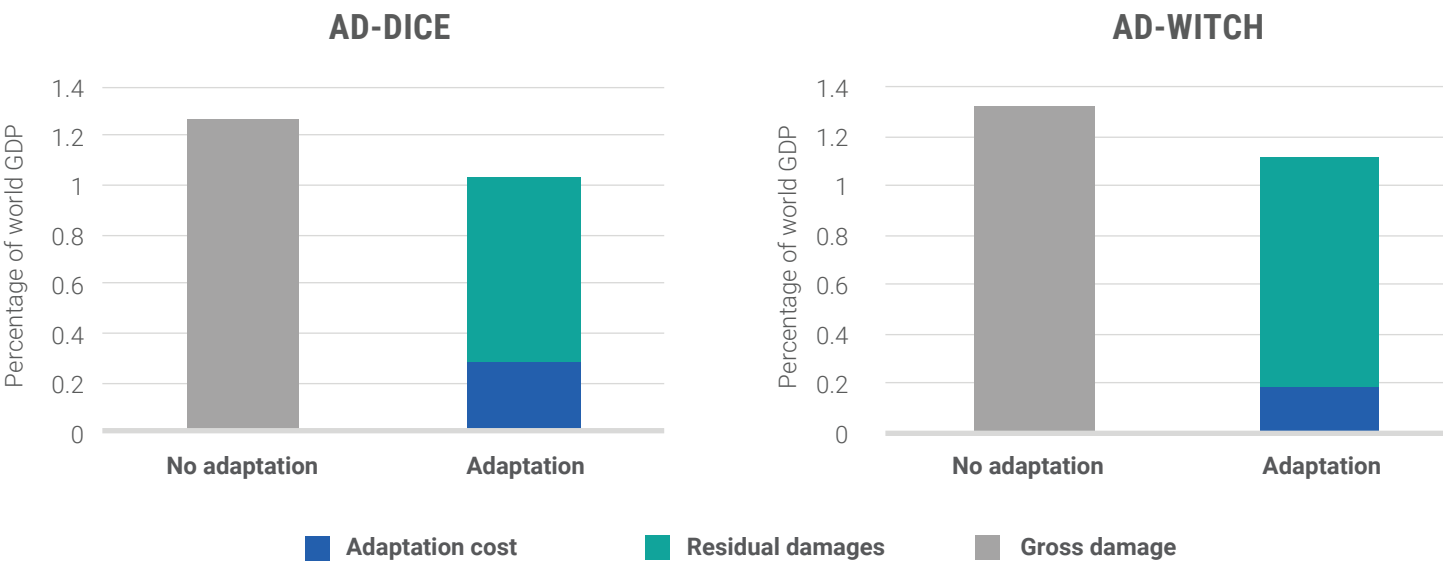
TABLE 1 Estimates of the Global Cost of Adaptation

STUDY	RESULTS (BILLION US$/YEAR)	TIME HORIZON CONSIDERED IN THE STUDY	METHODOLOGY AND COMMENT
World Bank, 2006	9–41	Present	Cost of climate proofing foreign direct investments, gross domestic investments and Official Development Assistance
Stern, 2007	4–37	Present	Update of World Bank (2006)
Oxfam, 2007	>50	Present	World Bank (2006) plus extrapolation of cost estimates from national adaptation plans and nongovernment organization projects.
UNDP, 2007	86–109	2015	World Bank (2006) plus costing of targets for adapting poverty reduction programs and strengthening disaster response systems
UNFCCC, 2007	50–170 globally (28-67 in developing countries)	2030	Planned investment and Financial Flows required for the international community
World Bank, 2010	70–100 (developing countries)	2050	Improvement upon United Nations Framework Convention on Climate Change (2007): more precise unit cost, inclusion of cost of maintenance and port upgrading, risks from sea-level rise and storm surges.
Integrated Assessments	Up to 430	2050	Global Economic Integrated Assessment models. Unclear baseline, Partial coverage, exclusion of uncertainty and policy costs.
UNEP 2014, 2016	280 to 500 (developing countries)	2050	Adjustment of World Bank (2010) by a factor 4 to 5, based on review of national studies.

Notes: UNDP: United Nations Development Programme; IFF: investment and financial flows; UNEP: United Nations Environment Programme (now UN Environment).

Sources: Watkiss, et al. 2014;[45] Chambwera et al. 2014.[46]

FIGURE 3 Composition of Climate Change Costs in Net Present Value under Optimal Adaptation and No Mitigation



Source: Agrawala et al. 2010.[48]

their income on food). Moving from a "poverty" scenario (slow growth, little progress on infrastructure service) to a "prosperity" scenario (rapid, inclusive, and climate-informed development) can reduce total economic losses from climate change from 2.6 percent to 2.2 percent of GDP by 2030. It would also reduce the number of people falling into poverty because of climate change from more than 100 million to less than 20 million (an 80 percent decrease).

4. Adaptation Faces a Myriad of Obstacles, of Which the Cost Is Only One

Adaptation often involves additional costs, but not all adaptation is costly. Adaptation sometimes can reduce climate change impacts without increasing costs; for instance when a new railway or new urban development is located in a different area to reduce its exposure to future sea level rise, or when better land tenure systems help people invest in their dwelling. Furthermore, adaptation actions sometimes reduce costs and investment needs; for instance when it is better not to build an infrastructure that will be exposed to unacceptable risks in the future, or when resilience is increased by removing distortive subsidies in the agriculture, water, or energy sector. It is crucial for adaptation efforts to include those no-cost or negative-costs options, which may not be costly but face other barriers and obstacles to implementation.[50] This section reviews these obstacles. In practice, however, the relative importance of these obstacles will vary across countries, sectors, and issues, and local analyses are required to develop an adaptation strategy based on the identification of relevant obstacles.

4.1 Financial Constraints Include Affordability Issues and Lack of Financing

Estimates of the cost of adaptation show that financial resources are likely a binding constraint to the implementation of many adaptation options. This is true not only for entire countries but also for households or firms. This is even more the case because poorer countries and people (as well as small firms) are the least likely to have access to borrowing, either due to high debt or lack of assets to use as collateral. They also are the least able to enter into complex financing arrangement (e.g., specialized bonds or Public-Private Partnerships for countries; insurance contracts for people or firms).

It is essential to identify whether the problem is linked to "funding" (the actor that wants or needs to act cannot afford to pay for the action) or to "financing" (the actor is able to afford to reimburse a loan but cannot access borrowing). When the problem is linked to financing, then nonconcessional loans for government and improved financial inclusion and capital market regulations can be sufficient to make adaptation possible. When the problem is funding, they (the actors) cannot afford to adapt, even with appropriate financing. In that case, grants or subsidized loans are required, and others (e.g., taxpayers or donors) have to pay if the adaptation action is to be made possible.

The need for subsidies to support adaptation can be minimized by improving access to (nonconcessional) financing, so that scarce concessional resources can be used for those who cannot afford to pay for adaptation. Sometimes, financial constraints can be relaxed by improving capital markets and building an enabling environment to facilitate private investments. For instance, improving tenure security can incentivize investment in housing, including in risk reduction and adaptation. In Peru, the issuance of property titles to over 1.2 million urban dwellers encouraged households to invest more in their homes, thereby reducing their vulnerability.[51] In some cases, access to financing can be facilitated by targeted subsidies, for instance by de-risking loans with first-loss agreement or guarantees.[52]

When private investments cannot be mobilized, especially in poor countries and communities, governments can invest in the provision of public goods services such as infrastructure or public services. Governments will need to directly invest in adaptation-related infrastructure (e.g., providing sanitation, especially to the poorest) or to support people directly, for instance, through direct cash transfers or subsidies to adaptation technologies. Since many governments lack the resources to invest in infrastructure or support their population, global climate finance and multilateral institutions have a key role to play, especially for the poorest. They can support countries by facilitating access to capital and know-how. They also can assist in integrating adaptation with development, and provide subsidies to the poorest countries or communities in close interaction with Official Development Aid, while ensuring that all development finance takes climate change into consideration.

However, one key message from this discussion paper is that financial constraint is only one of the many dimensions that should be considered in the design of an adaptation strategy. If spending efficiency is low because of nonfinancial obstacles to good decision-making, it could be inefficient or even counterproductive (leading to maladaptation) to just spend more. For instance, if coastal protections are poorly designed—either built in the wrong place, or with the wrong performance standard, or without being complemented with land-use plans and early warning systems—spending more on them may lead to an absolute increase in risk levels. The following subsections review other possible obstacles to facilitate their identification at the country or local level.

4.2 Market Failures Distort Incentives for Private Actors to Adapt

Adaptation is often considered a private good, since the benefits from adapting to climate change generally benefit the individual or entity that adapts. Nevertheless, it also faces market failures such as externalities, information asymmetry, and moral hazards. If all adaptation benefits were private goods, we could expect people and firms to autonomously adapt to climate change with little or no public intervention. Some adaptation actions, however, create public goods and, in this case, the party who invests cannot capture the gains from the investment, thereby reducing the incentive to act. For instance, a homeowner who reduces runoff by reducing soil artificialization will generate large gains for her/his neighbors and reduce investment needs in drainage infrastructure for the municipality. Classically, such actions will not receive appropriate levels of private investment.

Many natural risks, especially in areas of geographically concentrated infrastructure and high density, also call for collective management. Because of various synergy effects, economic production and infrastructure tend to agglomerate geographically, often in at-risk zones such as coastal areas or river flood plains. Moreover, protection infrastructure is "lumpy," meaning that it cannot be increased continuously and progressively—it often consists of a complex system (such as multiple rings of dikes and pumping stations), has large up-front costs, and usually covers large areas. As a consequence, individuals or firms cannot provide hard protection to their houses or production facilities independent of what is put in place at the collective level.

Finally, there are pure externalities, since adaptation actions by one household, firm, or even country may create higher damages for others. One typical example is with trans-boundary waters, when increased irrigation in one country creates water scarcity downstream. Across-sector effects also exist. For instance, increased water use for irrigation may affect power generation and ecosystems, as well as the livelihoods that depend on them.

Adaptation to climate change sometimes can be facilitated by new technologies, which face the usual set of challenges. In particular, the private sector tends to invest less in innovation and research than what would be socially desirable—because innovation incurs high risks and the ability to capture the benefits from an innovation is uncertain. For instance, research and development in agriculture is small compared to the challenges facing the sector, and public support has been declining.[53] Similarly, there is little research on many (especially tropical) diseases that may become more common with climate change.[54] In addition, technologies often struggle to move from the laboratory to the first pilot projects, where the real or perceived risks are highest. Governments, international organizations, and climate finance have therefore a role to play in supporting the early phases of technology creation and diffusion, including with support to niche markets or subsidies for first movers.

4.3 Governance and Government Failures Impair Public Action

Governments and local authorities face their own barriers to action, often referred to as government or regulatory failures. Governments may have access to insufficient resources or limited adaptation capacity, especially in poorer countries and where governments have limited access to capital markets and are unable to fund projects, even when they are cost-efficient. There can also be coordination failures within the government. Many adaptation options require multi-ministry actions, which create governance challenges (e.g., the reduction of flood risks may require some prevention measure implemented by the environmental ministry and an insurance scheme regulated by the ministry of finance). Furthermore, the spatial scope of the appropriate adaptation action may be different from the administrative boundary responsible for managing the problem, such as when urban adaptation can be made less expensive through actions upstream in a river basin.

Another obstacle to adaptation is that its benefits, even when significant, are largely invisible because they consist mostly of avoided losses.

Another obstacle to adaptation is that its benefits, even when significant, are largely invisible because they consist mostly of avoided losses. While catastrophes make headlines and lead to in-depth analyses to understand what went wrong, extreme weather events that lead to no or minor damages do not attract much interest. Understanding the benefit of action would require identifying the crises that are avoided, thanks to previous policies or measures, something that is hard to do. The invisibility of adaptation benefit has two consequences. First, good practices and innovative solutions may be overlooked, and the full extent of adaptation taking place in the world may be underestimated. Second, and most importantly, decision-makers who have implemented adaptation actions that prevented a disaster are rarely rewarded for it, which reduces the incentive to invest significant effort and political and financial capital into adaptation.[55] This stands true, particularly when the cost of adaptation action is visible and when a well-identified group of people are negatively affected by it. For example, it is particularly difficult to implement flood zoning, because it immediately reduces the wealth of a small number of landowners, while its benefits are in the future, uncertain, and widely distributed.

Frequently, government action is driven by narrow interest groups and is not in the public interest, and poor people are often deprived of the resources they need in order to adapt by the governance system. When it comes to adaptation and coping, the affected populations must have access to and some control over the country's economic, social, and institutional resources. Because poor communities lack human and social capital (like social networks and influence on policies and strategies that impact well-being), they are typically excluded from accessing such resources. It has been argued that only with inclusive and participatory decision-making processes can policies be designed to protect the poor and vulnerable effectively.[56] When such processes fail, as they often do in conflict-affected states, governments may be unwilling or unable to support those affected, with poor people being the first to suffer.

4.4 Lack of Information, Behavioral Biases, and Deep Uncertainty Lead to Paralysis

Whether or not people and firms have the right incentives to act and adapt to climate change, they may lack the information required to do so. Lack of information can include that which relates to current and future climate risks, and information and data on the environment in general. For instance, most developing country cities do not have the high-resolution topography data required for flood modeling. While the cost of these data is limited— less than a few million U.S. dollars per city—this lack of data is a bottleneck that impairs risk management and the appropriate design of water, transport, and housing assets in the billions of dollars. Another usual information constraint relates to the technologies and solutions that are available. Because information has aspects of a public good, it is underprovided by private actors and states, and therefore international organizations have a large role in producing and disseminating it.

Whether or not people and firms have an incentive to act and can access the information they need, they may still not act due to cognitive or behavioral biases. Individual decision-making, in practice, can differ significantly from some basic assumptions of economic theory. The variance arises partly from the limited time and capacity people have to process information on risks. Instead of carefully considering the costs, benefits, risks, and uncertainty, they may use simple rules of thumb (e.g., acting only after a loss) or heuristics (e.g., doing what the neighbors are doing, or as was done in the past).[57] In particular, people are biased toward the status quo and tend to opt for the default option. This bias means that people may not change their behavior when new risk appears, or when new information on existing risk becomes available, even when it would be desirable for them. Individuals, furthermore, often disregard the possibility of bad futures, possibly due to the stress created by thinking about them, thus making them unrealistically optimistic.[58] As a result, people may make decisions against their own interests and preferences.

Sometimes, decisions regarding adaptation to climate change involve deep uncertainty, often leading to gridlock and lack of consensus, strong political opposition to any action, and therefore to paralysis. These cases occur when experts cannot agree on which models to use (e.g., disagreement across climate models); on the probability distributions of key uncertain parameters (e.g., the probability of achieving the temperature target of the Paris Agreement); or on the values of alternative outcomes (e.g., the acceptability of a total loss of the Amazon forest or the valuation of mortality and mobility impacts).[59] In such cases, it may be impossible to define a probability for alternative outcomes or even to identify the set of possible futures (including highly improbable events, such as the famous "black swan").[60] These situations are particularly difficult to manage when large and irreversible damages are possible and may lead to complete paralysis, unless some specific decision-making approaches are mobilized that are better able to manage uncertainty and disagreement.[61,62,63]

Conclusions

Defining priorities for adaptation actions requires going beyond the identification of the (additional or full) costs of adaptation, so as to understand—in a given location and for a given sector—why the current situation or level of action is not satisfactory (or why the future situation is expected to be nonsatisfactory). If public or private stakeholders do not face the right incentives to act, do not have the information they need to act, cannot access the required technologies, or cannot determine the right course of action, simply increasing the amount of funding will not deliver the expected results.

With inadequate incentives or poor information on current and future risks, spending more on adaptation could backfire and lead to maladaptation. For instance, if incentive structures tend to favor hard protection against floods at the expense of land-use management and nature-based options, increasing investments in adaptation could lead to over-reliance on dikes and sea walls, creating major vulnerabilities to large sea level rise or an increase in river flood risks. There is evidence—in the absence of appropriate land-use regulations—that hard protections have led to increases in risk levels.[64,65]

With adequate incentives, better information and decision-making, investment needs for adaptation will be minimized, especially in terms of public resources. This is because removing the obstacles discussed earlier would ensure that all public and private investments are designed taking into consideration climate and disaster risks, thus reducing the need for public intervention.

Actions that remove obstacles to climate change adaptation are most likely to have a transformational impact and should be prioritized in terms of financing and action. The World Bank strategy on the use of climate finance suggests a focus on projects with transformational impacts, defined as projects that remove (or significantly reduce) the obstacles to the implementation of future climate change adaptation and resilience projects.[66] This recommendation does not imply that financing should not be made available before all obstacles are removed; rather, it suggests that financing should be used to support the removal of obstacles.

Actions that remove or reduce the obstacles to climate change adaptation can be expected to deliver large development co-benefits that go beyond reduced impacts of climate change. For example, improving the capacity of municipalities to develop better urban plans—plans that consider natural hazards such as floods, high temperature, or high pollution episodes—could be considered as an adaptation action but would also lead to cities that are less congested, more productive, and more livable. Stronger social safety nets implemented to help people manage increasingly intense droughts can also serve as the backbone of a social protection system that will protect people against all sort of shocks (from disease to crop failure), as well as help them escape poverty in a sustainable manner. In addition, while better designed and maintained infrastructure would be more resilient to climate change and natural hazards, they also would also be more reliable, thus reducing the cost that frequent power or water outages impose on firms and households.

The urgent need to adapt to climate change may be the political trigger that makes it possible to confront the fundamental issues that, in any event, need confronting, thereby generating broad benefits. The obstacles to adaptation are often also obstacles to sustainable development. Since the impacts of these obstacles are not always highly visible, tackling them is not always at the top of the political agenda. By shedding light on the hidden costs of these barriers and gathering political will and momentum to address them, the adaptation process also will make economies more efficient and productive, and societies fairer and more prosperous.

ENDNOTES

1. Chambwera, M., et al. 2014. "Economics of Adaptation." 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 of Climate Change* [Field, C., B. et al. (eds.)]. Cambridge, United Kingdom and New York, USA: Cambridge University Press, pp. 945–977. www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap17_FINAL.pdf.
2. World Bank. 2013. *World Development Report 2014: Risk and Opportunity: Managing Risk for Development.* Washington, DC: The World Bank. https://openknowledge.worldbank.org/handle/10986/16092.
3. Hallegatte, S., et al. 2015. *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Washington, DC: The World Bank. doi:10.1596/978-1-4648-0673-5. https://openknowledge.worldbank.org/bitstream/handle/10986/22787/9781464806735.pdf?sequence=13.
4. IPCC (Intergovernmental Panel on Climate Change). 2014. *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* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. Geneva: Intergovernmental Panel on Climate Change.
5. World Bank. 2018. "Series: Turn Down the Heat." www.worldbank.org/en/topic/climatechange/publication/turn-down-the-heat.
6. Neumayer, E., and F. Barthel. 2011. "Normalizing economic loss from natural disasters: a global analysis." *Global Enviromental Change* 21: 13–24. www.lse.ac.uk/website-archive/GeographyAndEnvironment/neumayer/pdf/Natdis_norm.pdf.
7. Hoeppe, P. 2016. "Trends in weather related disasters: Consequences for insurers and society." *Weather and Climate Extremes* 11: 70–79. www.sciencedirect.com/science/article/pii/S2212094715300347.
8. Hallegatte, S. 2017. "A normative exploration of the link between development, economic growth, and natural risk." *Economics of Disasters and Climate Change* 1: 5–31.
9. Hallegatte, S., A. Vogt-Schilb, M. Bangalore, and J. Rozenberg. 2016. *Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters*. Washington, DC: The World Bank.
10. IPCC, *2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 582 pp.
11. Mekonnen, M. M., and A. Y. Hoekstra. 2016. "Four billion people facing severe water scarcity." *Science Advances* 2(2): e1500323–e1500323.
12. Damania, R., et al. 2017. *Uncharted Waters: The New Economics of Water Scarcity and Variability*. Washington, DC: The World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/28096/9781464811791.pdf.
13. Barbier, E. B. 2014. "Climate change mitigation policies and poverty." *Wiley Interdisciplinary Reviews: Climate Change* 5: 483–491.
14. Barbier, E. B., and J.P. Hochard. 2018. "The Impacts of Climate Change on the Poor in Disadvantaged Regions." *Review of Environmental Economics and Policy* 12: 26–47.
15. TEEB. 2010. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB.* www.teebweb.org/publication/mainstreaming-the-economics-of-nature-a-synthesis-of-the-approach-conclusions-and-recommendations-of-teeb/.
16. Costanza, R., et al. 2014. "Changes in the global value of ecosystem services." *Global Environmental Change* 26: 152–158. https://community-wealth.org/sites/clone.community-wealth.org/files/downloads/article-costanza-et-al.pdf.
17. Rockström, J., et al. 2009. "A safe operating space for humanity." *Nature* 461: 472–475. www.researchgate.net/publication/268036589_A_Safe_Operating_Space_for_Humanity.
18. Hallegatte, S., et al. 2015. *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Washington, DC: The World Bank. doi:10.1596/978-1-4648-0673-5. https://openknowledge.worldbank.org/bitstream/handle/10986/22787/9781464806735.pdf?sequence=13.
19. Hallegatte, S., et al. 2015. *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Washington, DC: The World Bank. doi:10.1596/978-1-4648-0673-5. https://openknowledge.worldbank.org/bitstream/handle/10986/22787/9781464806735.pdf?sequence=13.
20. Schelling, T. C. 1992. "Some Economics of Global Warming." *American Economic Review*. 82: 1–14.
21. McGray, H., A. Hammill, R. Bradley, L. Schipper, and J.-E. Parry. 2007. *Weathering the Storm: Options for Framing Adaptation and Development*. Washington, DC: World Resources Institute. http://pdf.wri.org/weathering_the_storm.pdf.
22. Klein, R. J. T., et al. 2014. "Adaptation opportunities, constraints, and limits." 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* [Field, C.B., et al. (eds.)]. Cambridge, United Kingdom, and New York, USA: Cambridge University Press. pp. 899-943. www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap16_FINAL.pdf.
23. Dow, K. et al. 2013. "Limits to adaptation." *Nature Climate Change* 3: 305–307.
24. Scussolini, P., et al. 2016. "FLOPROS: An evolving global database of flood protection standards." *Natural Hazards and Earth System Sciences* 16: 1049–1061. www.nat-hazards-earth-syst-sci.net/16/1049/2016.
25. Hallegatte, S., C. Green, R.J. Nicholls, and J. Corfee-Morlot, 2013. "Future flood losses in major coastal cities." *Nature Climate Change* 3(9): 802–806.

26. Slovic, P., and E. Peters, 2006. "Risk perception and affect." *Current Directions in Psychological Science* 15: 322–325. https://pdfs.semanticscholar.org/1f8e/da951d2ba1b49c278427200b0a6754340bee.pdf.
27. Sjoberg, L. 2000. "Factors in Risk Perception." *Risk Analysis* 20(1): 1–12. www.researchgate.net/publication/271767735_Factors_in_risk_perception.
28. Hallegatte, S., A. Vogt-Schilb, M. Bangalore, and J. Rozenberg. 2016. *Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters*. Washington, DC: The World Bank.
29. Rigaud, K. K., et al. 2018. *Groundswell*. Washington, DC: The World Bank. http://documents.worldbank.org/curated/en/846391522306665751/pdf/124719-v2-PUB-PUBLIC-docdate-3-18-18WBG-ClimateChange-Final.pdf.
30. Lincke, D., and J. Hinkel. 2018. "Economically robust protection against 21st century sea-level rise." *Global Environmental Change* 51: 67–73.
31. Hinkel, J., et al. 2018. "The ability of societies to adapt to twenty-first-century sea-level rise." *Nature Climate Change* 8(7): 570–578.
32. Cervigni, R., R. Liden, J.E. Neumann, and K.M. Strzepek. 2015. *Enhancing the Climate Resilience of Africa's Infrastructure: The Power and Water Sectors*. Conference Edition. Washington, DC: The World Bank. doi:10.1596/978-1-4648-0466-3. www.worldbank.org/content/dam/Worldbank/Feature%20Story/Africa/Conference%20Edition%20Enhancing%20Africas%20Infrastructure.pdf.
33. Park, J. 2015. "Will We Adapt? Temperature Shocks, Labor Productivity, and Adaptation to Climate Change in the United States (1986-2012)." Discussion Paper 16–81. Cambridge, MA (USA): Harvard Kennedy School. www.belfercenter.org/sites/default/files/legacy/files/dp81_jpark_hpca.pdf.
34. Deryugina, T., and S. Hsiang. 2014. *Does the Environment Still Matter? Daily Temperature and Income in the United States*. NBER Working Paper Series No. 20750. Cambridge, MA (USA): National Bureau of Economic Research. www.nber.org/papers/w20750.
35. Hsiang, S. M., and D. Narita. 2012. "Adaptation To Cyclone Risk: Evidence From the Global Cross-Section." *Climate Change Economics* 03(02): 1250011. www.researchgate.net/publication/235959506_Adaptation_to_Cyclone_Risk_Evidence_from_the_Global_Cross-Section.
36. Schlenker, W., and M. J. Roberts. 2009. "Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change." *Proceedings of the National Academy of Sciences* 106(37): 15594–15598. www.pnas.org/content/pnas/106/37/15594.full.pdf.
37. Burke, M., and K. Emerick. 2016. "Adaptation to Climate Change: Evidence from US Agriculture." *American Economic Journal: Economic Policy* 8(3): 106–140. www.aeaweb.org/articles?id=10.1257/pol.20130025.
38. Damania, R. et al. 2017. *Uncharted Waters: The New Economics of Water Scarcity and Variability*. Washington, DC: The World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/28096/9781464811791.pdf.
39. Watkiss, P., et al. 2014. "The cost and benefits of adaptation: Results from the ECONADAPT project." Policy Report.
40. Hallegatte, S., C. Green, R.J. Nicholls, and J. Corfee-Morlot, 2013. "Future flood losses in major coastal cities." *Nature Climate Change* 3(9): 802–806.
41. Ward, P. J., et al. 2017. "A global framework for future costs and benefits of river-flood protection in urban areas." *Nature Climate Change* 7: 642–646.
42. Georgeson, L., M. Maslin, M. Poessinouw, and S. Howard. 2016. "Adaptation responses to climate change differ between global megacities." *Nature Climate Change* 6: 584–588.
43. GoF (Government of Fiji), World Bank, and GFDRR (Global Facility for Disaster Reduction and Recovery). 2017. *Climate Vulnerability Assessment—Making Fiji Climate Resilient*. Washington, DC: The World Bank. http://documents.worldbank.org/curated/en/163081509454340771/pdf/120756-WP-PUBLIC-nov-9-12p-WB-Report-FA01-SP.pdf.
44. Watkiss, P., et al. 2014. "The cost and benefits of adaptation: Results from the ECONADAPT project." Policy Report.
45. Chambwera, M., et al. 2014. "Economics of adaptation." 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 of Climate Change* [Field, C. B., et al. (eds.)]. Cambridge, United Kingdom and New York, USA: Cambridge University Press, pp. 945–977. www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap17_FINAL.pdf.
46. Agrawala, S., et al. 2010. "Plan or React? Analysis of Adaptation Costs and Benefits Using Integrated Assessment Models." Environmental Working Papers No. 23. Paris: OECD Publishing. www.cakex.org/sites/default/files/documents/5km975m3d5hb-en.pdf.
47. Hallegatte, S., et al. 2015. *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Washington, DC: The World Bank. doi:10.1596/978-1-4648-0673-5. https://openknowledge.worldbank.org/bitstream/handle/10986/22787/9781464806735.pdf?sequence=13.
48. Chambwera, M., et al. 2014. "Economics of adaptation." 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 of Climate Change* [Field, C. B., et al. (eds.)]. Cambridge, United Kingdom and New York, USA: Cambridge University Press, pp. 945–977. www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap17_FINAL.pdf.
49. Field, E. 2007. "Entitled to Work: Urban Property Rights and Labor Supply in Peru." *The Quarterly Journal of Economics* 122(4): 1561–1602.

50. Pardey, P. G., J. M. Alston, and C. Chan-Kang. 2013. "Public agricultural R&D over the past half century: An emerging new world order." *Agricultural Economics* 44(1): 103–113.

51. Trouiller, P., et al. 2001. "Drugs for neglected diseases: A failure of the market and a public health failure?" *Tropical Medicine and International Health.* 6(11): 945–951. https://pdfs.semanticscholar.org/a907/b6a51aee8731bb72a4bf6a3bfb620a0ecb61.pdf.

52. These ideas are fully aligned with the "maximizing finance for development" (MFD) approach adopted by the World Bank Group. The MFD approach asks the institution to "help countries maximize their development resources by drawing on private financing and sustainable private sector solutions to provide value for money and meet the highest environmental, social, and fiscal responsibility standards, and reserve scarce public financing for those areas where private sector engagement is not optimal or available." The objective of MFD is to encourage private sector participation, while leveraging and reserving scarce public dollars for critical public investments.

53. World Bank. 2013. *World Development Report 2014: Risk and Opportunity: Managing Risk for Development*. Washington, DC: The World Bank. https://siteresources.worldbank.org/EXTNWDR2013/Resources/8258024-1352909193861/8936935-1356011448215/8986901-1380046989056/WDR-2014_Complete_Report.pdf.

54. Tschakert, P. 2015. "The Role of Inequality in Climate-Poverty Debates." Policy Research Working Paper 7677. The World Bank. Washington DC. https://openknowledge.worldbank.org/handle/10986/24515.

55. Weber, E. U., and E. J. Johnson. 2012. "Psychology and Behavioral Economics. Lessons for the Design of a Green Growth Strategy." Policy Research Working Paper 6240. Washington, DC: The World Bank. www.researchgate.net/publication/256037586_Psychology_and_Behavioral_Economics_Lessons_for_the_Design_of_a_Green_Growth_Strategy.

56. Banerjee, A. V., and E. Duflo. 2011. *Poor Economics: A Radical Rethinking of the Way to Fight Global Poverty*. New York: PublicAffairs.

57. Lempert, R. J., D. G. Groves, S. W. Popper, and S. C. Bankes. 2006. "A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios." *Management Science* 52(4): 514–528.

58. Taleb, N. N. 2007. *The Black Swan: The Impact of the Highly Improbable*. New York: Random House.

59. Kalra, N., et al. 2014. "Agreeing on Robust Decisions: New Processes for Decision Making under Deep Uncertainty." Policy Research Working Paper No. 6906. Washington, DC: The World Bank. http://documents.worldbank.org/curated/en/365031468338971343/pdf/WPS6906.pdf.

60. Hallegatte, S. 2009. "Strategies to adapt to an uncertain climate change." *Global Environment Change* 19: 240–247. http://agwaguide.org/docs/Hallegatte-2009.pdf.

61. Jones, R. N., et al. 2014. "Foundations for decision making." 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* [Field, C. B., et al. (eds.)] pp 195–228. Cambridge, United Kingdom and New York, USA: Cambridge University Press.

62. Burby, R. J. 2001. "Flood Insurance and Floodplain Management: The US Experience." *Global Environmental Change Part B: Environmental Hazards* 3(3–4): 112–122. www.sciencedirect.com/science/article/pii/S1464286702000037.

63. Burby, R. J., A. C. Nelson, and T. W. Sanchez. 2006. "The Problems of Containment and the Promise of Planning." In *Rebuilding Urban Places after Disaster: Lessons from Hurricane Katrina,* pp 47–65. Philadelphia: University of Pennsylvania Press. www.researchgate.net/publication/46534111_The_Impact_of_Rules_on_Economic_Activity.

64. World Bank. 2018. *Prioritizing the Use of Concessional Finance to Maximize Climate Action*. Washington, DC: The World Bank. http://documents.worldbank.org/curated/en/879251537779825585/pdf/130066-REPLACEMENT-PUBLIC-WBG-Strategic-Use-of-Climate-Finance-Sept2018.pdf.

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Under the leadership of Dr. Patrick Verkooijen, the Global Center strategically focuses on bridging gaps in knowledge, serving as a resource for technical expertise, and helping to guide investments in adaptation solutions. Broadly, its mission is to accelerate knowledge-sharing, investments in people, and financing of solutions to ensure that building resilience becomes a higher priority at all levels of decision-making.

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World Resources Institute, led by Dr. Andrew Steer, is a global research organization that addresses challenges at the nexus of the environment, economy and human well-being. WRI pursues adaptation strategies to assist governments, civil society and the private sector to develop solutions in line with the scale and scope of climate change, and to support and engage vulnerable populations.

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