



Economic Aspects of Adaptation to Climate Change

**COSTS, BENEFITS
AND POLICY INSTRUMENTS**



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Edited by

Shardul Agrawala and Samuel Fankhauser



ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Foreword

Climate change poses a serious challenge to social and economic development in all countries. Clearly, while there is a need to negotiate international commitments to reduce greenhouse gas emissions, it is also important to undertake policies and measures that facilitate adaptation to the observed and projected impacts of climate change.

It is within this context that the OECD has undertaken work on adaptation since 2002. While the initial focus has been on the opportunities and challenges facing successful integration of climate risks in development co-operation and in domestic OECD contexts, more recent work has focused on analytical issues concerning the economics of adaptation. The present volume, *Economic Aspects of Adaptation to Climate Change: Costs, Benefits, and Policy Instruments*, is an output from this work.

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List of Abbreviations

ADB	Asian Development Bank
CDM	Clean Development Mechanism
CEE	Central and Eastern Europe
CGE	Computable General Equilibrium
EBRD	European Bank for Reconstruction and Development
EC	European Commission
EEA	European Environment Agency
ENSO	El Niño Southern Oscillation
FDI	Foreign Direct Investment
FONDEN	<i>Fondo para Desastres Naturales</i>
fSU	former Soviet Union
GDI	Gross Domestic Investment
GDP	Gross Domestic Product
GHG	Greenhouse gas
GNP	Gross National Product
IMF	International Monetary Fund
IPCC	Intergovernmental Panel for Climate Change
LDCs	Least Developed Countries
MAF	Mean annual flow
MDB	Murray Darling Basin
MENA	Middle East and North Africa
MPCI	Multi-peril crop insurance
NAPA	National Adaptation Programmes of Action
NASFAM	National Smallholder Farmers' Association of Malawi
NGO	Non-governmental organisation
NOAA	National Oceanic and Atmospheric Administration (United States)
ODA	Official Development Assistance
PES	Payment for ecosystem or environmental services
PPP	Public Private Partnership
PFI	Private Finance Initiative
R&D	Research and development
ROH	Risk of hunger
SRES	Special Report on Emission Scenarios (of IPCC)
SSA	Sub-Saharan Africa

UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
WB	World Bank
WFP	World Food Programme
WHO	World Health Organization
WUAs	Water user associations
WWF	World Wildlife Fund

Executive Summary

Adaptation to climate change is now widely recognised as an equally important and complementary response to greenhouse gas (GHG) mitigation in addressing climate change. Adaptation consists of deliberate actions undertaken to reduce the adverse consequences, as well as to harness any beneficial opportunities. A wide range of adaptation measures can be implemented in response to both observed and anticipated climate change. Such measures include altering farming practices and crop varieties, building new water reservoirs, enhancing water use efficiency, changing building codes, investing in air-conditioning, and constructing sea walls. Adaptation measures are undertaken both by public and private actors through policies, investments in infrastructure and technologies, and behavioural change. How much adaptation might cost, and how large its benefits might be, are issues that are increasingly relevant both for on-the-ground projects, as well as in a global context where trade-offs might need to be considered between the costs of climate policies and the residual damages resulting from climate change.

This report provides a critical assessment of adaptation costs and benefits in key climate sensitive sectors, as well as across sectors at the sectoral, national and global levels. It also moves the discussion beyond cost estimation to examining market and regulatory mechanisms that can be used to incentivise adaptation actions. Such mechanisms have so far received little attention in the context of adaptation.

Adaptation efforts need to rest on a sound economic basis

From an economic perspective, adaptation could be evaluated in terms of whether, and by how much, the benefits of such actions exceed the costs incurred. In particular, estimates of adaptation costs and benefits are relevant at two levels. First, adaptation costs and benefits are relevant for actors directly exposed to particular climate risks who need to make decisions about whether, how much, and when to invest in adaptation. These actors could include individuals and households, farmers, project managers, and

sectoral planners. Second, at the national and global level, cost estimates can be used to establish aggregate adaptation “price tags” that would then need to be met through international, domestic, and private funding sources.

There are, however, significant analytical and policy challenges associated with estimating adaptation costs and benefits. One reason is the nebulous nature of many adaptation actions, which are often embedded within responses undertaken to a broader set of social and environmental stimuli. It might, therefore, not be feasible to cost the climate component of such decisions that are also simultaneously conditioned by a whole range of other, and often more influential, factors. Adaptation costs may also increase several-fold if, in addition to measures that directly reduce climate damages, measures to improve baseline “adaptive capacity” are also included within the purview of adaptation. Uncertainty about the specific effects of climate change will also influence adaptation costs and benefits, as will the timing of the actions that are undertaken. There might also be significant differences between direct and economy-wide consequences of adaptation measures. These considerations, therefore, need to be borne in mind while interpreting particular empirical estimates of adaptation costs and benefits.

Sectoral adaptation costs and benefits estimates are available, but their coverage is uneven

There is a relatively large amount of information available about adaptation costs at the sectoral level, although it is unevenly distributed across sectors. In particular, there is a significant body of literature accumulated since the early 1990s on assessing adaptation in coastal zones, including on the costs and benefits of such measures. These studies reveal that the cost estimates for optimal levels of protection are typically relatively modest in normalised terms, although in absolute terms these still represent a significant investment. In the agricultural sector, studies have focused on quantifying the benefits of adaptation strategies and provide limited information on the costs of such measures. A general finding from the global-level studies is that relatively modest adaptation measures can significantly offset declines in projected yield as a result of climate change. However, adaptation benefits will vary depending on crop type and may not translate equally to all regions. In the case of coastal zones and agriculture there is also fairly comprehensive geographical coverage. By contrast, the information on costs of adaptation is much more limited and diffuse for the water resources, energy, infrastructure, tourism and public health sectors and limited largely to developed country contexts. Such information is also very context specific making broader generalisations difficult.

Some adaptations can be implemented at low cost but others, such as infrastructural measures, will require significant investment

Sectoral studies have shown that in some sectors some adaptation actions can lead to high benefit-cost ratios and/or be implemented at low cost. For example, farm level adjustments, which are assumed to cost very little, can lead to significant benefits in terms of offsetting damages. This is also the case for other behavioural adaptations, such as enhanced water use efficiency. On the other hand, many adaptations inevitably involve “hard” or infrastructural measures, such as water storage reservoirs and desalinisation and waste water treatment facilities in the case of the water sector. Likewise, infrastructural solutions are prevalent in coastal zones, with coastal protection measures, such as dykes and sea walls, representing the main adaptation options considered. Infrastructure adaptation costs are also key in systems that are already critically at risk from immediate climate change impacts, such as high latitude and high altitude systems.

Adaptation costing studies have tended to focus more on these “hard” adaptation measures, as they are easier to cost than behavioural and policy measures. This may lead to a bias towards structural measures and a neglect of potentially critical “soft” measures needed to facilitate adaptation (such as better land use planning), and lead to inappropriate and costly adaptation actions. It may also result in overestimation of adaptation costs. On the other hand, other aspects of existing studies may actually result in underestimation of the costs of adaptation. For example, costing studies in coastal zones typically only consider adaptation to gradual sea level rise and do not consider storm surges or extreme scenarios of sea level rise. The consideration of extreme events in addition to changes in mean conditions is likely to significantly increase the costs of adaptation. For these reasons it is important that not too much emphasis is placed on particular estimates of costs of adaptation strategies, as such a focus could distort policy priorities.

Global studies of adaptation costs are also available, but face very serious limitations

Until recently there were no empirical estimates of the global costs of adaptation across multiple sectors, but five assessments have explicitly confronted this issue since mid-2006. These studies suggest that adaptation to climate change at the global level will cost several USD billion per year. While potentially relevant for the international discussion on adaptation and its financing, existing global multi-sectoral estimates face serious limitations. In particular, the results are quite sensitive to the assumptions

made with regard to the exposure of assets and investments to climate change and the costs of “climate-proofing” them. Very little or no analytical information is currently available on either of these parameters and, therefore, the assumptions that are made become particularly critical, given the very large magnitude of baseline investments to which these percentages are applied. Further, in most cases the estimates do not have a direct attribution to specific adaptation activities, nor are the benefits of adaptation investments articulated. There are also issues of double counting, and scaling up to global levels from a very limited (and often very local) evidence base. Successive studies have also tended to stack upon the assumptions made in preceding studies and the results are consequently not truly independent. Therefore, the “consensus”, even in order of magnitude terms, is premature. For all these reasons “headline” global adaptation cost numbers can be seriously misleading if adequate attention is not paid to the assumptions that underlie particular empirical estimates.

Adaptation policy is about much more than costing and financing, establishing incentives is also critical

While the policy debate has focused on the cost of adaptation, ways to raise public adaptation funding, and allocation of adaptation costs, much less attention has been given to the role of market and regulatory mechanisms in facilitating adaptation. This is particularly critical given that a majority of actions are undertaken by private actors and also because the scope of the adaptation challenge will far exceed the public budgets available to address it. While some adaptations provide public benefits, such as protection of coastal areas from sea level rise, many others will offer more private benefits that accrue to individuals or firms, or to a consortium of such actors. In theory, the latter set of actions should be autonomous. Self-interest should be a sufficient incentive for such individuals or groups to undertake adaptive measures that reduce their vulnerability. Like the activities of markets, these actions do not have to be directed centrally by a public authority. However, as in the case of markets, governments are called upon to provide an enabling environment that allows private agents to make timely, well-informed and efficient adaptation decisions. Where private actions fail because of external effects of other failures, governments may also have to provide adaptation as a public good. Conversely, the scale and/or efficiency of many adaptations typically undertaken by governments could be enhanced through engagement with the private sector. Policy instruments need to be put in place to catalyse such engagement and to ensure that it leads to the desired outcomes. These instruments can be directed at using markets, creating markets, regulation and legal

arrangements, and engaging the public. A range of policy instruments are relevant to adaptation in many sectors, including insurance schemes, price signals/markets, financing schemes via Public Private Partnerships (PPPs), regulatory incentives, and research and development incentives. Insurance schemes, price signals and environmental markets, and PPPs for infrastructure as well as research and development are explored further in this report.

Insurance can incentivise adaptation if premiums are well designed; it is, however, not a panacea

Insurance has a dual role with respect to adaptation. Access to insurance payouts can lessen the net adverse impact of climatic events on policy holders. At the same time, insurance is also an instrument for incentivising adaptations aimed at reducing climate risks. Properly set insurance premiums can, in principle, send appropriate signals to policy holders to undertake adaptation measures to reduce exposure to various risks, including those posed by climate change. On the other hand, poorly designed premiums that do not adequately reflect the underlying risk can actually impede adaptation or even promote maladaptation. Insurance owes its popularity to notions of economic efficiency, risk aversion, and a sense of solidarity at times of hardship. It is also good business. The insurance sector has already been forced to evolve in order to cope with new varieties of environmental risk. As climate changes and historical weather records become less useful, the insurance sector will have to develop new ways of assessing risk and spreading it away from those affected, while encouraging those at risk to adapt to the new environment. Insurance can play a prominent role in any adaptation strategy, covering risks, such as crop failure, snow coverage and the impact of freak weather events (*e.g.* floods, storms, hurricanes and heat waves). However, there are a number of reasons why its impact on adapting to climate change may be limited. First, as long as climate impacts are uncertain, insurance companies will overcharge for climate risk or refuse coverage of risks that might otherwise be insurable. Second, budget constraints, inertia and cultural factors will prevent people from adapting fully in the short term. Third, insurance cover is by no means universal. It is especially patchy among poor households and in poor countries. Public policy measures will likely be needed to overcome these market imperfections. For example, they may take the form of publicly funded adaptation measures to bring risks down to an acceptable level. Alternatively, government could subsidise the most extreme layer of risk to cover low probability high consequence events. Public policy should not, however, subsidise systemic risks, as it may reduce incentives to move away

from activities that become progressively less viable under the changing climate.

Price signals and environmental markets can be used to promote adaptation actions but may require adjustments to internalise adaptation benefits

Climate change will add to the pressures and “baseline” stress factors already affecting natural resources, such as water, forests and other ecosystems. Baseline stress from pollution, overexploitation and mismanagement has many causes, but at the root of it is the fact that property rights over natural resources are ill defined and their services are not valued properly in the market. Economic theory has a ready-made solution to overcome these market failures. The external benefits of natural resources have to be given a market value, either by factoring them into the price (*e.g.* through environmental charges) or by creating environmental markets. There is vigorous discussion about the extent to which these economic mechanisms are actually effective in practice. There are questions about social outcomes of trading schemes, with issues about the equity of access to markets and the potential market dominance of important players. The report focuses on water pricing, water markets and payment for ecosystem or environmental services (PES) and how they can encourage and promote adaptation behaviour. From an adaptation point of view environmental markets and pricing – for water, forests or other ecosystem services – serve two main purposes. They reduce baseline stress (making systems more resilient) and they allow to internalise, or give value to, the adaptation benefits provided by ecosystems, for example in terms of coastal protection. For the first purpose it is not necessary to adjust market mechanisms specifically for adaptation. However, adaptation will be one more reason to increase the scale and scope for markets in water, forestry and other ecosystem services. For the second purpose, adjustments in the design of environmental markets may be needed in order to monetise the adaptation benefits of ecosystems and ensure allocative efficiency of those markets.

Public private partnerships can help provide infrastructure for adaptation and help “climate-proof” existing infrastructure

Adaptation will put a considerable strain on government resources. Faced with either operational or financial constraints (or both), governments often look to the private sector to enhance their ability to provide public

services. Well-designed PPPs can help overcome operational constraints, enhance performance and accelerate investment. PPPs are essentially about the efficient and fair allocation of risks (and rewards) between public and private partners. Climate change is just another risk factor, albeit an increasingly important one, that has to be taken into account alongside regulatory, commercial, macroeconomic and other risks. In applying private infrastructure schemes to climate change adaptation two main questions arise. The first question is how current and future PPPs can be adjusted to climate-proof the investments they make. The second is whether these schemes are suitable to finance, build and operate dedicated climate protection schemes, such as flood barriers and coastal defences. Regarding the first question, private infrastructure schemes should be well suited to deal with this additional risk so far as the institutional arrangements to analyse, mitigate and allocate it are put in place. At the same time, miscalculation of risks is one of the main reasons why PPPs fail. It would, therefore, be wise to build responsibility for adaptation into the contracts to the extent possible. This could, for example, take the form of technical specifications to climate-proof a structure or – perhaps better – clear performance standards that incentivise the private operator to invest in adaptation. Regarding the second question, there are currently no private infrastructure projects that explicitly provide climate protection. However, the concept is sufficiently broad and well established to extend easily to dedicated adaptation infrastructure. A potential advantage of PPP schemes is that they provide the ability to finance projects outside the government budget. This is potentially very important given the large adaptation needs in infrastructure, although fiscal sustainability constraints may impose limitations on the use of the instrument. There is, therefore, a need for careful cost-benefit analysis and project appraisal for adaptation infrastructure.

Chapter 1

Putting Climate Change Adaptation in an Economic Context

Shardul Agrawala and Samuel Fankhauser

Adaptation to climate change is now widely recognised as an equally important and complementary response to greenhouse gas mitigation in addressing climate change. Adaptation consists of deliberate actions undertaken to reduce the adverse consequences, as well as to harness any beneficial opportunities. A wide range of adaptation measures can be implemented in response to both observed and anticipated climate change. How much adaptation might cost, and how large its benefits might be, are issues that are increasingly relevant both for on-the-ground projects, as well as in a global context where trade-offs might need to be considered between the costs of climate policies and the residual damages resulting from climate change. This chapter provides a context for examining adaptation costs and benefits, and discusses key issues related to the timing of adaptation decisions as well as how such decisions could be affected by the uncertainty surrounding the impacts of climate change. It also moves the discussion beyond cost estimation to examining market and regulatory mechanisms that can be used to incentivise adaptation actions. Such mechanisms have so far received little attention in the context of adaptation.

Introduction

Adaptation to climate change is now widely recognised as an equally important and complementary response to greenhouse gas (GHG) mitigation. Both mitigation and adaptation help to reduce the risks of climate change. Mitigation – through the reduction in sources or enhancement of sinks of greenhouse gases – reduces all impacts of climate change. Adaptation – through adjustments in human and natural systems to actual or expected climatic changes – can be selective. It can reduce negative impacts, and take advantage of the positive. Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation essential, particularly in addressing near term impacts.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) defines adaptation as any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2007). The process of adapting to climate and climate change is both complex and multifaceted. As such it is very difficult to do adaptation analytical justice, and a number of typologies have been developed to classify adaptation activities. For example, adaptation measures have been classified according to: timing (anticipatory *vs.* reactive); scope (local *vs.* regional, short-term *vs.* long-term); purposefulness (autonomous *vs.* planned); and adapting agent (natural systems *vs.* humans, individuals *vs.* collective, private *vs.* public).

While societies have a long record of adapting to the impacts of weather and climate, many regions and sections of the society remain poorly adapted even to current climate. Further, climate change poses novel risks often outside the range of historical experience. These include: increases in mean temperatures and sea levels; changes in precipitation patterns; melting of glaciers and permafrost; and changes in the intensity and/or frequency of weather extremes such as droughts, heat waves, floods and hurricanes. There are now some examples of adaptation measures that also incorporate considerations of climate change, but progress remains limited in both developing and developed country contexts (Agrawala and van Aalst, 2008; Gagnon-Lebrun and Agrawala, 2007).

In planning for these observed and anticipated impacts of climate change it is important that adaptation efforts rest on a sound economic basis. How much adaptation might cost, and how large its benefits might be, are issues that are increasingly relevant both for on-the-ground projects, as well as in national and global contexts where trade-offs might need to be

considered between the costs of climate policies and the residual damages resulting from climate change.

There are significant analytical and policy challenges associated with economic assessments of both mitigation and adaptation. However, the boundaries of mitigation measures are more clearly defined, the literature on mitigation costs is much more comprehensive, and there is a clear metric (reduction in GHG emissions) for assessing the effectiveness of such measures. In contrast, what does and does not fall within the purview of adaptation is much more ambiguous, the literature on adaptation costs remains sparse and contested, and there are no accepted metrics for assessing the effectiveness of adaptation policies and measures.

Unlike mitigation, which has to be co-ordinated internationally, adaptation decisions are largely decentralised. They will be made to a large extent in well-established decision-making contexts, such as corporate investment or local government planning. Some adaptations will have a public good character and as such may be provided by the state (local authorities or national governments). In making these adaptation decisions the authorities will apply traditional decision support tools, such as cost-benefit analysis, cost-effectiveness analysis and multi-criteria analysis.

Other, perhaps most, adaptation decisions will be taken by private agents, such as individuals and firms. The more sophisticated actors among them will base their decision on the investment appraisal techniques of corporate finance. They may, for example, calculate the net present value of an adaptation investment, analyse its risks and returns or determine the return on capital employed. What these decisions have in common is that they are based, loosely, on a comparison of the advantages and disadvantages – the costs and benefits – of a certain course of action (Mendelsohn, 2000). In addition to the level and type of adaptation, decision makers will also have to determine the timing of their action. Both sets of decisions – level and timing – will be taken under considerable uncertainty about the precise impacts of climate change. Finally, because adaptation is a decentralised process, there is the question whether, and if so how, economic agents need to be incentivised to adapt. This is a question for public policy.

The costs and benefits of adaptation

The comparison of costs and benefits, while straightforward conceptually, raises a plethora of methodological issues including valuation, discounting as well as aggregate versus distributional consequences. Such issues are hardly unique to adaptation, but the challenge of addressing them

is particularly acute in this context. One reason for this is the nebulous nature of many adaptation actions, which are often embedded within responses undertaken by innumerable private and public actors to a broader set of social and environmental stimuli. For example, farming practices, land use planning and infrastructure design might all reflect some considerations of current climate and anticipated climate but it might not be feasible to cost the climate component, as such decisions are also simultaneously conditioned by a whole range of other (and often more influential) factors. Separating the costs of adapting to climate variability and climate change adds a further layer of complexity, as few examples of adaptation are as cut and dry as building the next increment of a sea wall to protect against climate change induced sea level rise.

Adaptation costs might increase several-fold if, in addition to measures that directly reduce climate damages, actions to increase baseline “adaptive capacity” – for example, investments in nutrition, education and health services – are also included within the purview of adaptation. Delineating the boundaries of adaptation to the climate component, therefore, is not straightforward.

Moreover, while adaptation can reduce negative impacts of climate change, there will nevertheless be residual damages. This is because, as the IPCC Fourth Assessment Report notes, there are biophysical, social, and economic limits with regard to the level and rate of climate change that different systems can adapt to (IPCC, 2007, Chapter 17). The gross benefit of adaptation is the difference between the climate damages with and without adaptation. Adaptation, however, will also entail costs. Consequently, these costs need to be deducted from the gross benefits to arrive at the net benefits of adaptation (Stern, 2006, after Fankhauser, 1998).

Table 1.1 helps to illustrate these issues. The starting point is the recognition that adaptation to climate phenomena is a part of everyday life. Today’s society is adapted to the current climate through measures ranging from farmland irrigation to flood protection infrastructure. This current state of affairs is represented in the top-left quadrant of the table. In the illustrative example of Table 1.1, society is spending an amount of 90 units on adaptive measures – for example, a flood protection system. Included in these costs are both monetary components (*e.g.* capital costs) and non-monetary components (*e.g.* the impact on the environment). This level of adaptation is sufficient to prevent most adverse climate effects, but not all. There is a residual damage of 50 units, for example due to occasional extreme flooding. There is no climate change, and hence no climate change impact yet. Current adaptation is preferred over extended adaptation, because the additional cost of more comprehensive protection ($150-90=60$)

are higher than the additional benefits of reduced flood damages at the margin ($50-20=30$).

The calculus changes with climate change (associated, for example, with a higher frequency of storms and floods). Under a changed climate, the extra costs of adaptation ($150-90=60$) are more than offset by the reduced costs of climate change ($200-120=80$). In this particular example, the climate change benefits alone are sufficient to justify adaptive action, but the extra reduction in ordinary climate impacts ($50-20=30$) is an important ancillary benefit. The ancillary benefits occur because the extended protection system will reduce the impact of both climate change-induced and ordinary floods.

Obviously, the example of Table 1.1 is simplistic and ignores important complications, such as uncertainty and continuous change. However, it helps to flesh out two important issues: the costs of adaptation have to be measured against current adaptive measures; and many adaptive measures may have climate change as well as non-climate-change-related benefits, although distinguishing between the two will not be possible in practice.

Table 1.1. A hypothetical classification of adaptation costs and benefits

	Current climate	Changed climate
Current adaptation	Adaptation cost: 90 Ordinary climate damage: 50 Climate change damage: 0	Adaptation cost: 90 Ordinary climate damage: 50 Climate change damage: 200
Extended adaptation	Adaptation cost: 150 Ordinary climate damage: 20 Climate change damage: 0	Adaptation cost: 150 Ordinary climate damage: 20 Climate change damage: 120
Net benefit of extended adaptation	Incremental adaptation cost: 60 Incremental adaptation benefit: $30+0$ Net benefit: -30	Incremental adaptation cost: 60 Incremental adaptation benefit: $30+80$ Net benefit: +50

Source: Adapted from Table 2.1 in Fankhauser, S., (1998), “The Cost of Adapting to Climate Change”, Working Paper No. 16, Global Environment Facility, Washington, DC.

The timing of adaptation

The long-term nature of climate change makes timing an important part of adaptation decisions. This is particularly the case for strategic and anticipatory means of adaptation. Like decisions about the level of adaptation, timing decisions will be based on the relative costs and benefits of taking action at different points in time. In particular, decision makers will compare the present value of adaptation now with the present value of adaptation at a later stage (Fankhauser *et al.*, 1999). The present value of taking action now consists of the cost of adaptation (for instance, the cost of

building and maintaining a sea wall), plus a stream of residual climate damages, since adaptation will not be perfect. The present value of acting in, say, ten years includes ten years of unabated climate impacts, the discounted adaptation cost ten years from now, and a stream of residual damages thereafter.

The timing decision thus depends on three factors. The first is the difference in adaptation costs over time. The effect of discounting would normally favour a delay in adaptation measures, and so would the prospect of potentially cheaper and more effective adaptation techniques that might be available in the future. However, there is also a class of adaptations where early action is cheaper. They include adjustments to long-term development plans and long-lived infrastructure investments, such as water and sanitation systems, bridges and ports. In each of these cases, it will be cheaper to make adjustments early, in the design phase of the project, rather than incur the cost and inconvenience of expensive retrofits.

The second factor is the short-term benefits of adaptation. Early adaptation will be justified if it has immediate benefits, for example by mitigating the effects of climate variability. It has been argued that changes in weather extremes will be one of the earliest signs of climate change, making adaptation to climate variability a potentially important early measure. Also in this category fall adaptations that have strong ancillary benefits, such as measures to preserve and strengthen the resilience of natural ecosystems. Another important example is health investments (for example, the development of a malaria cure), which have poverty-alleviation benefits that are at least as large as the climate change benefits.

The third component has to do with the long-term effects of early adaptation. Early adaptation is justified if it can lock in lasting benefits, for example by preventing long-term damage to ecosystems. Depending on these three factors, actors will decide to act earlier or later. However, unlike in the example in the previous section, they will have to make their decision under considerable uncertainty with regard to the magnitude and timing of the impacts of climate change. Under such circumstances, perceptions about the potential risks faced and benefits of adaptation become critical. Timely or effective adaptation will not occur if there is either a lack of perception in the mind of the actor of a need for action or a lack of perception of a benefit from the action (Hanemann, 2008). Timing errors can occur in both directions – premature or too late – and both will have implications for the costs and benefits of adaptation.

Dealing with uncertainty

Uncertainty about the exact nature of climate change impacts at the local and regional level (for example in terms of precipitation and storminess) makes it difficult to fine-tune adaptation measures. Adaptation decisions will be taken under uncertainty. Conceptually, this means that most of the adaptation benefits (avoided climate impacts) in Table 1.1 should be interpreted as expected benefits, that is, the probability-weighted mean over the range of possible outcomes. Risk-averse decision makers may pay more attention to negative outcomes, and if the potential cost of inaction is substantial, adaptation decisions may be based on the precautionary principle.

One set of adaptation measures that are easy to agree on, even in the face of uncertainty, are win-win measures. These are adaptations that are justifiable even in the absence of climate change. Many measures to deal with climate variability, for example long-term weather forecasting and early warning systems, may fall into this category. Schelling (1992) has argued that one of the best adaptation measures available would be (sustainable) economic development, and it is easy to agree that better health care, access to safe drinking water and improved sanitary conditions for the world's poorest households are clear win-win measures.

Fankhauser *et al.* (1999) have argued that given the prevailing uncertainties, the best way to account for potential climate change in current investment decisions may be to increase the flexibility and robustness of systems – allowing them to function under a wide range of climatic conditions and withstanding more severe climatic shocks.

The call for increased flexibility and robustness applies to physical, natural and social systems. In the case of physical capital, the capacity of water storage systems may be increased in anticipation of future droughts, for example, or coastal protection measures may be strengthened to withstand more severe storms and floods. In the case of natural capital, measures to protect the environment may increase the ability of species to adapt to a changing climate. Institutionally, creating regulatory frameworks that encourage individual adaptability would help to increase the flexibility and robustness of economic systems.

Incentivising adaptation

Costing adaptation, by itself, is not enough. Raising money is important, but policies need to be in place to ensure that the money is well spent. Adaptation will comprise of thousands of actions by households, firms,

governments, and civil society. Sustainable adaptation requires successful internalisation of both current and anticipated climate risks in the various decisions, while being mindful of the associated uncertainties. Despite a long record of dealing with climate variability there is considerable literature showing that many societies and sectors remain poorly adapted, even to current climate. Further, while there are now some examples of adaptation to long term climate change, progress in this direction has been more at the level of planning than actual implementation on the ground. There are clearly several bottlenecks here, not in the least, access to adequate financial resources and relevant climate information. Both financing and climate information have consequently been the focus of considerable attention.

What has received much less attention, however, is the role of market and regulatory mechanisms in scaling up and/or enhancing the efficiency of adaptation efforts. This is a particularly critical gap, given that a majority of actions are undertaken by private actors and also because the scope of the adaptation challenge will far exceed the public budgets available to address it.

Across all sectors of the economy, private firms have a key role to play in adaptation. Engineering and construction, for instance, will be at the forefront of climate-proofing infrastructure and the housing stock. Telecommunications, information technology and the media have a key role to play in hazard monitoring and communicating risk. Agribusiness will be involved in securing food supplies in a warmer world. The banking sector will have to finance adaptation investments, while the insurance sector will provide risk coverage. Climate change might also pose risks to the global supply chain for many products, and might consequently need to be reflected in business planning. Even beyond the locus of firms and businesses, adaptation considerations also need to be better reflected in decisions made by individual actors. These decisions could be with regard to consumption of resources, such as water, whose scarcity might be exacerbated under climate change. Such decisions could also include investments, such as climate-proofing of homes and purchase of insurance, which might influence the vulnerability of individuals and households to climate change impacts.

In theory, such actions should be autonomous. Self-interest should be a sufficient incentive for such actors to undertake measures that reduce their vulnerability to climate risks or to exploit potential business opportunities. Like the activities of markets, these actions do not have to be directed centrally by a public authority. In fact this would be counter-productive, and probably impossible. However, as in the case of markets, governments have a role to play in providing an enabling environment that allows private agents to make timely, well informed and efficient decisions. Public policy

also has a role to play in case private adaptations by one actor or set of actors create negative externalities on other sections of the society or the environment. Governments also have a role to play in providing adaptation as a public good where private actions might not occur due to externalities or other failures. Conversely, the scale and efficiency of many adaptations typically undertaken by governments could be enhanced through engagement with the private sector. Again, mechanisms need to be in place to catalyse such engagement and to ensure that it leads to the desired outcomes.

Focus of the remainder of this volume

This volume provides an assessment of both adaptation costs and benefits as well as the role of economic and policy instruments in facilitating adaptation. Chapter 2 of this volume first examines empirical estimates of adaptation costs and benefits in different climate sensitive activities and regions including coastal zones, agriculture, water resources, energy demand, infrastructure, tourism and public health. The chapter then assesses available aggregate cross-sectoral estimates of adaptation costs at the global level and in certain national contexts. An overall assessment is then provided of the key messages, strengths and limitations of the sectoral, national and global estimates of adaptation costs and benefits.

Chapter 3 examines the role of economic and policy instruments in incentivising adaptation. First, an overview of typical climate change impacts and adaptation strategies in key climate sensitive sectors is used to identify key policy instruments that could be used to facilitate adaptation. Next, three instruments are identified which could play a particularly key role in adaptation: insurance, price signals and environmental markets, and PPPs. Insurance is a recurring instrument within the context of adaptive responses in a number of sectors. Price signals and environmental markets might be critical to adaptation within the context of many climate sensitive natural resources, including water and ecosystems. PPPs could potentially play a very critical role in financing and enhancing the climate resilience of infrastructure, as well as in research and development for adaptation technologies in agriculture. These three instruments are discussed sequentially in the remainder of the chapter with a particular focus on their nature and current use, strengths and limitations, and relevance for adaptation.

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Chapter 2

Empirical Estimates of Adaptation Costs and Benefits: A Critical Assessment

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Empirical estimates of costs and benefits can serve as a key criterion for making decisions on adaptation. They can also be useful for establishing “price tags” for overall adaptation needs that would then need to be met through international, domestic, and private funding sources. There is a relatively large amount of information on adaptation costs at the sectoral level, although it is unevenly distributed. Studies for coastal zones show that while significant investment will be needed for coastal protection, total costs of protection represent a relatively small percentage of national Gross Domestic Product (GDP). However, there are significant regional differences and the normalised protection costs might be significantly higher for certain regions. In the agricultural sector, a general finding from available studies is that relatively modest adaptation measures can significantly offset declines in projected yield as a result of climate change, although these benefits depend upon the crop, growing region, and level of climate change. For the other sectors there are only a few isolated estimates of adaptation costs and benefits. Aggregate, multi-sectoral studies on costs of adaptation are also becoming available at the global level and, in some cases, at the national level. While potentially relevant from a policy perspective, available global and national estimates of adaptation costs have significant limitations: scaling up to aggregate levels from a limited (and very local) evidence base; issues of both under counting as well as double-counting; and finally lack of clear articulation of the benefits of the adaptation measures that are costed.

Introduction

Assessment of adaptation costs and benefits is driven, in principle, by two objectives. First, adaptation costs and benefits are relevant for sectoral or project level decision makers exposed to particular climate risks who need to make decisions about whether, how much, and when to invest in adaptation. The optimisation that is sought here is how to minimise the total costs of climate change – composed here of the cost of adaptation investments and the cost of residual damages. Costs can also serve as a key – but not the only¹ – criterion for selecting amongst competing adaptation measures. Such information has the potential to be of direct operational relevance at the sectoral and project level. In fact, most of the studies on adaptation costs and/or benefits are at the sectoral or project level. Second, at the international level, cost estimates can be used to establish “price tags” for overall adaptation needs that inform policy makers (and climate negotiators). They would then need to be met through international, domestic, and private funding sources. The precise benefits of such measures are usually not quantified. This is a relatively new and rapidly developing area of analysis, with many of the key results having emerged only since 2006.

This chapter provides a critical assessment of adaptation costs and benefits that address both the above mentioned objectives. The next section discusses the empirical estimates of adaptation costs and benefits in various climate sensitive activities/regions including coastal zones, agriculture, water resources, energy demand, infrastructure, public health, and tourism. The following section assesses available national level cross-sectoral cost estimates of priority adaptation actions identified in the National Adaptation Programmes of Action (NAPAs) of the Least Developed Countries (LDCs). The penultimate section then evaluates the results and underlying assumptions of a number of estimates of the global, multi-sectoral costs of adaptation that have become available since 2006. These include estimates published by the World Bank, Stern Review, Oxfam, the United Nations Framework Convention on Climate Change (UNFCCC), and the United Nations Development Programme (UNDP). Finally, the last section provides an overall assessment of the key messages, strengths and limits of the sectoral, national, and global estimates of adaptation costs and benefits.

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1. Other criteria might include social acceptability, ease of implementation, ancillary effects, and long-term viability.

Sectoral estimates

Although sectoral and project level assessments offer fewer headline estimates than global assessments of adaptation costs, they generally offer more insight into the specific adaptation responses that are being costed compared to multi-sectoral assessments at the global and national levels, which are much more abstract. Therefore, information on sectoral climate change impacts and costs/benefits of measures should, in principle, provide the basis for higher order assessments.

There is a relatively large amount of information available about adaptation costs and benefits at the sectoral level, although it is unevenly distributed across sectors (Table 2.1). In particular, there is a significant body of literature accumulated since the early 1990s on assessing adaptation in coastal zones, including on the costs and benefits of such measures. Significant work has also been done on quantifying the benefits of adaptation strategies in agriculture, although very limited information is available on the costs of such measures. There is also literature in the energy sector on costing enhanced energy demand for air-conditioning and reduced demands for space heating as a result of warmer temperatures, to the extent such responses fall within the purview of adaptation. Beyond that, the literature on adaptation costs and benefits is both diffuse and limited, with a small number of local studies in water resources, health, infrastructure, and tourism.

Table 2.1. Coverage of sectoral estimates of adaptation costs and benefits

Sector	Coverage	Cost estimates	Benefit estimates
Coastal zones	Comprehensive – covers most coastlines	✓	✓
Agriculture	Comprehensive – covers most crops and growing regions	–	✓
Water	Isolated case studies in specific river basins	✓	✓
Energy (Demand for space cooling and heating)	Primarily North America	✓	✓
Infrastructure	Cross-cutting issue – covered partly in coastal zones and water resources. Also isolated studies of infrastructure in permafrost areas.	✓	–
Health	Very limited	✓	–
Tourism	Very limited – winter tourism	✓	–

The following sections review sectoral estimates of adaptation costs and benefits for coastal zones, agriculture, water resources, energy demand, infrastructure, tourism and public health. The precise structure of each section is dependent on the type of studies available. For example, while the discussion on coastal zones is more skewed towards adaptation costs the section on agriculture has a primary focus on adaptation benefits and has only very limited information on costs, in view of the available literature. Likewise there is fairly comprehensive geographical coverage in the case of coastal zones and agriculture, which makes some broad conclusions possible. However, the discussion on energy demand is largely limited to the United States, while only sporadic and largely local level information on adaptation costs and benefits is available for water resources, public health, tourism and infrastructure.

Coastal zones

Climate change will have complex impacts on coastal zones that will exacerbate existing pressures. Anticipated climate related changes include: an accelerated rise in sea level; further rise in sea surface temperatures; an intensification of tropical and extra tropical cyclones; larger extreme waves and storm surges; altered precipitation/run-off; ocean acidification; and degradation of coastal ecosystems. A majority of studies on climate change and coastal zones have focused narrowly on sea level rise. Consequently, studies estimating costs of adaptation in coastal zones have tended to focus on costs of adaptation to sea level rise, which is expected to reach 18-59 cm by the end of the 21st century (IPCC, 2007a, Chapter 10). This range, however, does not include uncertainties associated with the potential melt of the Greenland and West Antarctic ice sheets, which could raise sea level by many metres in the long run (Oppenheimer *et al.*, 2007). In addition, due to the slow response of sea level rise to changes in climate, there is already a certain “commitment to sea level rise” irrespective of future cuts in greenhouse gas emissions. Given these long-term trends and the long lifetime of coastal structures, anticipatory adaptation to sea level rise becomes even more critical over the near and medium term.

Adaptation in coastal zones

Adaptation in coastal zones can take a wide range of forms, including planned retreat, coastal protection, beach nourishment, “flood-proofing”, property insurance and changes in water management and aqua/agriculture. In general, there are three broad types of adaptation strategies:

- **Protect:** aims to protect the land from the sea so that existing land uses can continue, by constructing hard structures (*e.g.* seawalls) as well as using soft measures (*e.g.* beach nourishment).
- **Accommodate:** increases society's ability to cope with the effects of the event. This strategy implies that people continue to occupy the land but make some adjustments (*e.g.* elevating buildings on piles, growing flood- or salt-tolerant crops).
- **Retreat:** reduces the risk of the event by limiting its potential effects. This strategy involves no attempt to protect the land from the sea. In an extreme case, the coastal area is abandoned.

A summary of the major physical impacts and potential adaptation responses to sea level rise is provided in Table 2.2.

Table 2.2. **Physical impacts and examples of potential adaptation responses to sea level rise**

Physical impacts		Examples of adaptation responses (P = protection; A = accommodation; R = retreat)
Inundation, flood and storm damage	a. Surge (sea)	Dikes/surge barriers (P) Building codes/floodwise buildings (A)
	b. Backwater effect (river)	Land use planning/hazard delineation (A/R)
Wetland loss (and change)		Land use planning (A/R) Managed realignment/forbid hard defences (R) Nourishment/sediment management (P)
Erosion (direct and indirect change)		Coast defences (P) Nourishment (P) Building setbacks (R)
Saltwater intrusion	a. Surface waters	Saltwater intrusion barriers (P) Change water abstraction (A)
	b. Groundwater	Freshwater injection (P) Change water abstraction (A)
Rising water tables and impeded drainage		Upgrade drainage systems (P) Polders (P) Change land use (A) Land use planning/hazard delineation (A/R)

Source: UNFCCC (United Nations Framework Convention on Climate Change) (2007), "Investment and Financial Flows to Address Climate Change", 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.

Empirical estimates of adaptation (protection) costs

The majority of studies assessing impacts of climate change on coastal zones have focused on impacts of, and adaptation to, sea level rise.

Table 2.3 summarises the results from a wide range of studies in different countries and regions, as well as at the global level. Typically, such cost estimates are based on models that seek to minimise the total costs of climate change, *i.e.* the costs of protection and the residual (unprotected) damages that will be incurred through loss of valuable endowments, such as land and natural habitats. The benefits in this case are the damages avoided as a result of protection. While not always reported explicitly, they are nevertheless a key component to computing optimal levels of protection. In regions with extremely valuable assets, total protection might indeed be optimal. In other cases, the optimal strategy might well be to invest in partial (or incomplete) protection and accept a certain amount of residual damages.

While Table 2.3 is clearly an abstraction and cannot fully capture all the complexities and nuances that might differentiate individual studies, three broad conclusions are nevertheless possible.

First, there is extensive information on adaptation costs for coastal regions worldwide, as well as on a global basis. Such costs though are only for coastal protection (as opposed to other possible adaptations), and have traditionally been estimated only for a 1 metre sea level rise.

Second, the reviewed studies show that optimal levels of coastal protection – defined as the percentage of coastline that is protected from sea level rise to minimise the total costs of sea level rise (*i.e.* costs of protection and residual damages) – are often quite high, if not total in most regions of the world. Exceptions include countries or regions where coastal land values are low (usually because of lower population densities) and therefore lower protection levels might be considered optimal.

Third, these studies show that the annualised cost estimates for optimal levels of protection are typically relatively modest in normalised terms, frequently less than 0.1% (or even 0.05%) of national GDP. However, adaptation costs may be high relative to the GDP of coastal areas, as it is not guaranteed that protection costs will be absorbed fully at the national level. There are also significant regional differences and the share of protection costs as a percentage of GDP will be significantly higher for certain small island states. For example, Nicholls and Tol (2006) estimate that adaptation will cost in the range of 5-13.5% of GDP for Micronesia under a range of scenarios for the 2080s.

Table 2.3. Costs of coastal protection

Regions/countries	Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (in USD billions, unless otherwise noted)	% GDP or GNP
World	Global	8.9-9.1 cm by 2030 (average); max 44.4-52.7 cm by 2080	Not available(N/A)	4-10.6	Not available (N/A)
	Tol, 2002	1 m	89% ⁷	10.55	N/A
	Tol <i>et al.</i> , 1998	1 m	88% ²	N/A	0.056% GNP ⁵ (average)
Europe and former Soviet Union (ISU)	OECD Europe	8.9-9.1 cm by 2030 (average); max 44.4-52.7 cm by 2080	N/A	0.62-1.79	N/A
	Europe	B2 (low sea level rise) and A2 (high sea level rise) scenarios for 2020 and 2080	N/A	EUR 1.3-4.0 billion for 2020 EUR 1.3-9.3 billion for 2080	N/A
	OECD Europe	1 m	86%	1.36	N/A
	CEE ISU	1 m	93%	0.53	N/A
	Western Europe	1 m	Total	1.6	0.02% GDP ⁴
	Northern and Western Europe		0 ²		0.02% GNP ⁵
	Baltic States		0 ²	N/A	0.08% GNP ⁵
	Northern Mediterranean	1 m	16% ²		0.02% GNP ⁵
	Former Soviet Union		0 ²		0.02% GNP ⁵
	Netherlands Poland	1 m	95% ²	N/A	0.05% GNP ⁵ 0.02% GNP ⁵

Table 2.3. Costs of coastal protection (cont.)

Regions/countries	Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (in USD billions, unless otherwise noted)	% GDP or GNP
North and Central America, Caribbean	OECD North America	8.9–9.1 cm by 2030 (average); max 44.4–52.7 cm by 2080	N/A	0.88–2.02	N/A
	OECD America	1 m			
	North America	1 m	77% Total	0.83 1.4	N/A 0.02% GDP ⁴
	North America	1 m	47% ²	N/A	0.02% GNP ⁵
	Central America	1 m	89% ²		0.23% GNP ⁵
South America and Latin America	Antigua	1 m	59% ²	N/A	0.32% GNP ⁵
	Latin America	8.9–9.1 cm by 2030 (average); max 44.4–52.7 cm by 2080	N/A	0.57–1.60	N/A
	Latin America	1 m	86% Total	1.47 0.12	N/A 0.01% GDP ⁴
	South American Atlantic Coast	1 m	88% ²	N/A	0.25% GNP ⁵
	South American Pacific Coast	1 m	89% ²		0.01% GNP ⁵
South America and Latin America	Guyana	20–35 cm by 2080s	N/A	N/A	0.1–0.4% GDP ⁶
	Nicholls and Tol, 2006				

Table 2.3. Costs of coastal protection (cont.)

Regions/countries	Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (in USD billions, unless otherwise noted)	% GDP or GNP
Africa and Middle East	Africa Middle East	8.9–9.1 cm by 2030 (average); max 44.4–52.7 cm by 2080	N/A	0.53–1.32 0.06–0.17	N/A
	Africa Middle East	1 m	80% 30%	0.92 0.05	N/A
	Middle East and North Africa	1 m	Total	0.44 0.17	0.08% GDP ⁴ 0.06% GDP ⁴
	Sub-Saharan Africa				
	Southern Mediterranean		88% ²		0.07% GNP ⁵
	African Atlantic Coast	1 m	89% ²	N/A	0.25% GNP ⁵
	African Indian Ocean Coast		89% ²		0.38% GNP ⁵
	Gulf States		79% ²		0.05% GNP ⁵
	Mozambique Guinea-Bissau	20–35 cm by 2080s	N/A	N/A	0.1–0.8% GDP ⁶ 0–0.6% GDP ⁶
	Egypt	1 m	–300% ^{2,3}	N/A	0.45% GNP ⁵

Table 2.3. Costs of coastal protection (cont.)

Regions/countries	Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (In USD billions, unless otherwise noted)	% GDP or GNP
Developing Asia	Nicholls, 2007 ¹	8.9–9.1 cm by 2030 (average); max 44.4–52.7 cm by 2080	N/A	0.80–2.18	N/A
South and South East Asia CPA	Tol, 2002	1 m	93% 93%	3.05 1.71	N/A
South East Asia East Asia Asia Indian Ocean Coast Indian Ocean Small Islands	Tol <i>et al.</i> , 1998	1 m	89% ² 87% ² 89% ² 88% ²	N/A	0.2% GNP ⁵ 0.06% GNP ⁵ 0.52% GNP ⁵ 0.72% GNP ⁵
Pacific Asia OECD Pacific Asia China India	Deke <i>et al.</i> , 2001	1 m	Total	1.9 1.4 0.7 0.5	0.05% GDP ⁴ 0.19% GDP ⁴ 0.2% GDP ⁴ 0.25% GDP ⁴
Maldives Vietnam Cambodia	Nicholls and Tol, 2006	20–35 cm by 2080s	N/A	N/A	0–0.2% GDP ⁶ 0–0.2% GDP ⁶ 0–0.1% GDP ⁶
Singapore	Ng and Mendelsohn, 2005	20–86 cm by 2100	Total	NPV in 2000 USD: 0.17–3.08 million	N/A

Table 2.3. Costs of coastal protection (cont.)

Regions/countries	Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (in USD billions, unless otherwise noted)	% GDP or GNP
Pacific	OECD Pacific	8.9–9.1 cm by 2030 (average); max 44.4– 52.7 cm by 2080	N/A	0.39–1.08	N/A
	OECD Pacific	1 m	95%	0.63	N/A
	Pacific Ocean Large Island	1 m	76% ²	N/A	0.17% GNP ⁵
	Pacific Ocean Small Island		88% ²		0.77% GNP ⁵
	Marshall Island		90% ²		>7.04% GNP ⁵
	Micronesia		85–99%		5–13.5% GDP ⁶
	Palau	20–35 cm by 2080s	65–95%	N/A	3.9–9.1% GDP ⁶
	Tuvalu		75–98%		0.9–2.2% GDP ⁶
	Marshall Islands		N/A		0.6–1.7% GDP ⁶
	French Polynesia		83–99%		0.4–1.0% GDP ⁶
	Nauru		N/A		0.2–0.6% GDP ⁶
	New Caledonia		43–93%		0.2–0.4% GDP ⁶
	Papua New Guinea		75–98%		0.2–0.4% GDP ⁶
	Kiribati		0–75%		0–1.2% GDP ⁶

Table 2.3. Costs of coastal protection (cont.)

Regions/countries		Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (in USD billions, unless otherwise noted)	% GDP or GNP
Other	Transition economies	Nicholls, 2007 ¹	8.9–9.1 cm by 2030 (average); max 44.4–52.7 cm by 2080	N/A	0.16–0.48	N/A

1. This study provides protection costs for mean sea level rise in 2030 and maximum sea level rise in 2080 under A1B and B1 scenarios. The cost range reported here is the minimum and maximum under both scenarios and time periods.
2. Percent decrease in the number of “people at risk” (population in the risk zone multiplied by the probability of flooding per year).
3. The number of people at risk increases because adaptation allows people to remain in areas that would otherwise be abandoned.
4. Percentage of 1990 GDP assumed to remain constant each year between 1990 and 2100. Values in 1990 USD.
5. Annual percentage undiscounted, assuming 100 years lifetime.
6. Protection costs as a percentage of current GDP under the four Special Report on Emission Scenarios (SRES) worlds (A1FI, A2, B1, B2) for 2080.
7. This protection level corresponds to the median protection level for the nine regions provided in the study (protection levels are given separately for each region).

Limitations of cost estimates

The studies reviewed above have divided the costs of sea level rise into three categories: capital costs of protective infrastructure, costs of dry land loss, and costs of wetland loss. This, however, is a relatively simplistic treatment of the impacts of climate change on coastal zones and of the costs and benefits associated with adaptation.

Specifically, the costing studies face four key limitations. First, they consider a very narrow scope of climate change impacts and adaptation within coastal zones. On the impacts side, typically only inundation of coastal zones and wetlands are considered in such costing studies. Not included are other impacts, such as saltwater intrusion which could affect surface and groundwater supply, increased disease risk, increased exposure to storm surge and flooding. Inclusion of such considerations may significantly alter the choice of optimal strategies and estimates of protection costs. For example, Kirshen *et al.* (2006) show that accounting for storm damages (in addition to mean sea level rise) may significantly alter the costs and benefits of various adaptation measures, and influence the choice of optimal adaptation strategies. The authors modelled the impacts of sea level rise and storm surges, and estimated the potential costs and benefits of different adaptation measures for the Boston metropolitan area. Thus, land use planning and flood-proofing were shown to be optimal for mean sea level rise, while coastal protection was the optimal response if storm surge was taken into account. Adaptation costing studies also typically do not consider costs of adapting to more extreme scenarios of sea level rise, as would be the case if there were to be rapid melting of the Greenland and West Antarctic ice sheets.

Only one study (Nicholls *et al.*, 2005) has examined the consequences for climate damages and protection costs associated with the collapse of the West Antarctic ice sheet, which could raise sea levels by up to five metres in the long term. A wide range of scenarios is examined ranging from an additional contribution of 0.5 metre per century to an extreme (and unlikely) additional five metres between 2030 and 2130. Under such extreme scenarios the costs of adaptation rise dramatically (by as much as a factor of 30) and the level of optimal protection declines from 85 to 50%. Conversely, the studies are also limited in terms of the scope of the adaptation responses that are costed. Costing is limited only to hard protection measures (such as dykes), and in some cases also includes beach nourishment. However, many other adaptation responses to sea level rise, such as land use planning and building codes, are very difficult to cost and have thus been excluded from such assessments.

Second, as noted previously, protection cost estimates are based on models that seek to minimise the total costs of climate change, *i.e.* the costs of protection and the residual (unprotected) damages that will be incurred through loss of valuable endowments, such as land. Clearly, assumptions about costs of protection investments and the economic value of endowments which are at risk are critical to the final results. Both these parameters are based on key assumptions – protection costs are typically extrapolated from specific local projects, while endowment values are often not accurately known or comprehensive enough. For example, according to one study the uncertainties surrounding endowment values can lead to a 17% difference in coastal protection, a 36% difference in the amount of land protected, and a 36% difference in direct cost globally (Darwin and Tol, 2001).

Further, endowment values are often assumed to be static and do not reflect dynamic market realities. For example, Yohe *et al.* (1996) note that in a situation where the real estate market firmly believes that coasts will not be protected by public authorities and that land should eventually be abandoned, the risk of sea level rise should be internalised and property should be depreciated in accordance with the evolving conditions and accruing information. Based on this reasoning, the authors demonstrate that a 30-year foresight, assumed to be sufficient to allow for efficient property market adaptation, would not only reduce optimal levels of protection but also the total cost of sea level rise (damages + protection costs) in unprotected areas by 22 to 70% for a one metre sea level rise for five coastal communities of the east coast of the United States. An additional study by Yohe and Schlesinger (1998) for the entire developed coastline of the United States found that the cost of sea level rise would be reduced by 25-33% on average if markets adjusted efficiently. Efficient market adaptation or perfect foresight, however, requires timely and complete information, which is unrealistic. The reality will lie between the no foresight and perfect foresight estimates.

Finally, most studies focus only on the direct protection costs to sea level rise and do not consider that the level of investment in protective structures will likely have an impact on capital markets and that the diminution of natural resources due to land losses may well negatively affect national economies. Therefore, sea level rise and the response measures implemented will likely have macro-economic effects, such as increases in price level and shifts in the demand for capital resources. A limited number of studies have used Computable General Equilibrium (CGE) models to assess the economy wide impact of land loss and increased protection investment in coastal zones (Darwin and Tol, 2001; Deke *et al.*, 2001; Bosello *et al.*, 2007). Although these studies are based on slightly different

assumptions² and are subject to significant limitations (in particular the uncertainties associated with projections of trade patterns and economic growth several decades into the future), they all conclude that there might be very significant divergence between direct costs and welfare losses, as well as in the regional distribution of these costs.

Agriculture

Climate change will impact agriculture in multiple ways. Changes in temperature and precipitation will affect the timing and length of growing seasons, as well as yields. These climatic changes will also affect water availability for agriculture. Increasing carbon dioxide concentrations, meanwhile, will have a positive effect on water use efficiency leading to higher yields for certain crops. Changes in climate variability, in particular changes in the intensity and/or frequency of floods, drought and storms, are also expected to significantly affect agricultural production. Regional yields are projected to increase up to 3°C of warming in mid to high latitudes, while they are expected to decline in low latitudes for any increase in temperature (IPCC, 2007b, Chapter 5). In Africa and especially in Sub-Saharan regions the agricultural production could decrease leading to a growing number of people at risk of hunger (Yates and Strzepek, 1998; Parry *et al.*, 2004; Winters *et al.*, 1998; Fischer *et al.*, 2002). Adaptation will, therefore, be of particular importance to dampen the adverse regional impacts, maintain food production and access in many developing countries.

Adaptation in agriculture

The agricultural sector has a long record of adapting to climate. To a large extent these measures will be implemented at the farm level through short-term production decisions including adjustments in planting dates, crop mixes, or in the intensity of input use such as fertiliser. However, these

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2. The Deke *et al.* (2001) study is restricted to the costs of coastal protection, ignoring land losses and its wider economic consequences. In addition, both Deke *et al.*'s and Darwin and Tol's (2001) studies model investments in coastal protection as a general loss of productive capital and ignore the induced investment demand for coastal protection and, thus, overstate the negative impacts of sea level rise (Bosello *et al.*, 2007). By contrast, Bosello *et al.* (2007) model coastal protection explicitly as an additional investment (thus including its demand effects) and assume that investing in coastal protection crowds out consumption rather than other investment (Bosello *et al.*, 2007). Finally, it is worth noting that while Deke *et al.* (2001) use a dynamic CGE model, Darwin and Tol (2001) and Bosello *et al.* (2007) use a static CGE model.

decisions will be largely influenced by the economic environment including market conditions and public policies. Public intervention will be important in providing a proper environment for adaptation, in particular by stimulating research and development, diffusing information and making markets and policy conditions conducive for efficient and sustainable adaptation. Table 2.4 outlines key farm and public level adaptations.

Table 2.4. **Adaptation strategies in agriculture**

Farm level	Public level
Crop and farm income insurance	Invest in research and development (<i>e.g.</i> develop heat resistant cultivars)
Diversification of production	Promote adoption of new technologies and practices
Adjust the timing of operations	Provide institutional support to diffuse information on climate change and adaptation possibilities (<i>e.g.</i> extension services, early warning systems)
Migration (move to cities or other rural regions)	Promote efficient use of resources (<i>e.g.</i> ensure market efficiency)
Adjust intensity of input use (<i>e.g.</i> fertiliser, irrigation)	Review policies to create an environment which is conducive for efficient and sustainable adaptation (<i>e.g.</i> water rights, environmental policies, trade policies, domestic support)
Adopt new production practices (<i>e.g.</i> conservation tillage)	
	Enhance agricultural trade to spread the impact of regional supply shortages over the international market

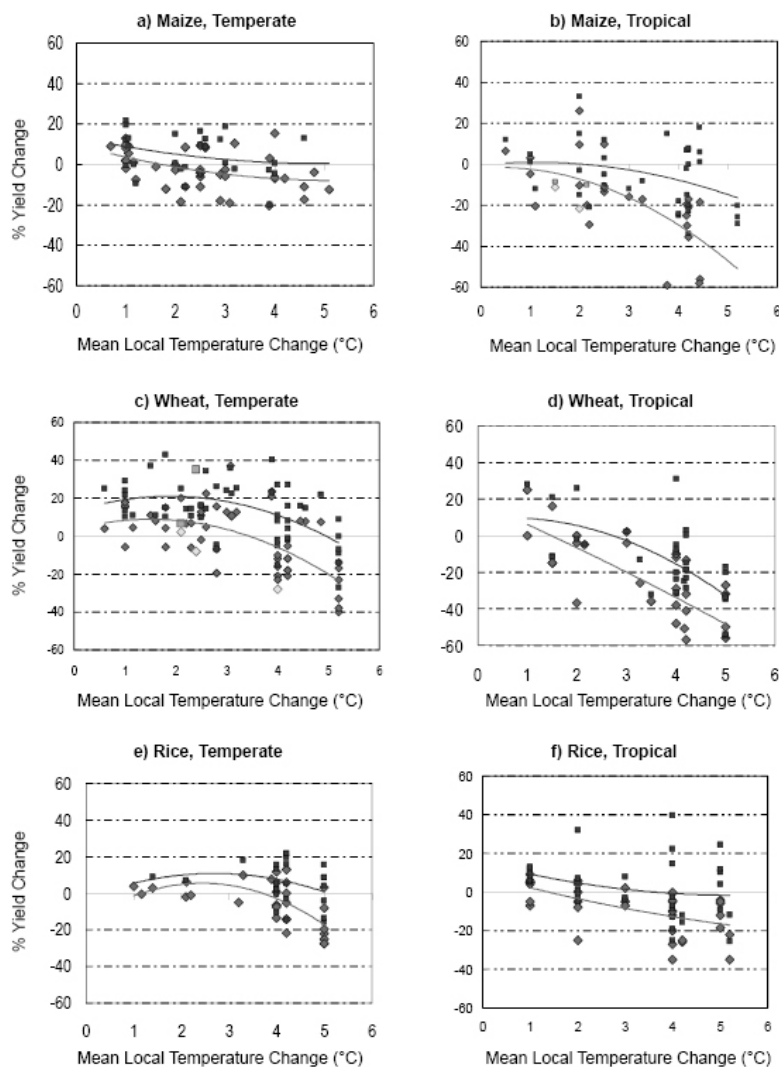
Given the complexity of agriculture and the multitude of decisions and actors involved, estimation of the costs and benefits of adaptation is an extremely challenging task. Two broad sets of approaches have been used, one focusing on crop impact models and how changes in management might affect yields, and the other looking at spatial analogues to examine the relationship between climatic factors and agricultural production. In both cases the literature has primarily focused on the assessment of the benefits of what are assumed to be low or no-cost adjustments in farming behaviour. Such estimates have been made from farm level studies, all the way to the global level. However, these benefits are not translated equally to all regions, all crops, or all levels of climate change. Aggregate estimates of adaptation costs in agriculture are relatively rare, although there are now some preliminary estimates of the magnitude of public investments that might be required to facilitate adaptation in agriculture.

Benefits and costs of adaptation in agriculture

The agricultural sector has been fairly well covered by the climate change adaptation literature. Salient studies include Reilly *et al.* (1994) and

Darwin *et al.* (1995), which looked at climate change and adaptation impacts on world agriculture and economy, as well as a global assessment by Rosenzweig and Parry (1994), which reported the impacts and adaptation benefits in terms of increased cereal production and food security. A general finding from the global-level studies is that relatively modest adaptation measures can significantly offset declines in projected yield as a result of climate change. Rosenzweig and Parry (1994) using the crop impact modelling approach concluded that such adaptations could offset yield declines by anywhere from 37.5 to 200%. Using spatial analogues, Darwin *et al.* (1995) computed global adaptation benefits to range from 78-90% of the initial impacts. However, their assessment of adaptation was relatively simplistic, leaving large uncertainties with regard to its true potential. Recent studies provide a more comprehensive treatment of adaptation by relaxing the assumptions of smooth climatic change and perfect foresight by decision makers, or using higher spatial resolution climate change scenarios. Tan and Shibasaki (2003), using a geographical-information-system-based crop model and allowing for modelling of inter and intra-regional bioclimatic differences, computed global adaptation benefits of low cost adjustments in the range of 23-48%.

There are also a large number of studies that assess the benefits of adaptation for different crops and regions. Figure 2.1 presents a synthesis from 69 published studies on the impacts of climate change on crop yields for maize, wheat and rice (IPCC, 2007b, Chapter 5). The adaptation measures considered in these studies include changes in planting dates, changes in cultivars, and shifts from rain-fed to irrigated agriculture. “Best fit” curves are shown for crop yields without adaptation (light, lower curve), and with adaptation (dark, upper curve). The adaptation benefit, in this figure, then is the difference between these two curves. More specific results from a select number of studies are shown in Table 2.5. A key message from these various studies is that farm level adjustments do yield significant adaptation benefits. However, such benefits do not translate equally to all regions, crops or levels of climate change. Some studies also suggested that even in the absence of financial or environmental constraints potential benefits of climate change adaptation could be significantly reduced by climate variability and imperfect information and decision-making processes.

Figure 2.1. Adaptation benefits for cereal crops in temperate and tropical regions¹

1. The adaptation benefits are shown as the difference between the lower (no adaptation) and upper (low cost adaptation) yield curves which are based on a synthesis of 69 published studies.

Source: Published with the permission of the Intergovernmental Panel on Climate Change; Easterling, W.E., *et al.* (2007), "Food, Fibre and Forest Products. Climate Change 2007: Impacts, Adaptation and Vulnerability", contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, in M.L. Parry *et al.* (eds.), *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, pp. 273-313.

Table 2.5. Quantified adaptation benefits in agriculture from selected studies

Study	Climate scenario	Area	Adaptation	Impacts		Adaptation benefits (% of impacts)
				Without adaptation	With adaptation	
Tan and Shibasaki, 2003	CGCM1/ for 2050	Asia	Changes in planting dates	-12%	Yield changes	33%
		North America		-23%	-8%	48%
		South America		-29%	-12%	38%
		Europe		-23%	-18%	43%
		Australia		-26%	-13%	27%
Butt <i>et al.</i> , 2005	CGCM, HADCM /for 2030	Africa		-35%	-19%	23%
					-27%	
			Heat resistant variety	Yield changes		63%
			Change in crop mix	-8.8%	-3.2%	29-33%
			Heat resistant variety	Welfare changes		33-34%
Njie <i>et al.</i> , 2006	HADCM3 /2010-39	The Gambia	Market adaptation	N/A	N/A	58%
			Full adaptation			90-107%
			Change in crop mix	Risk of hunger (ROH) decreases		7-11%
			Heat resistant variety			0-1%
			Market adaptation	N/A	N/A	7-14%
			Full adaptation			30-35%
			Changes in crop mix	Yield changes (kg/ha)		13%
			Increased fertiliser use	1 294	1 294	33%
			Irrigation	1 141	1 517	37%
			Minimal/survival irrigation		1 563	9%
					1 247	

Table 2.5. Quantified adaptation benefits in agriculture from selected studies (cont.)

Study	Climate scenario	Area	Adaptation	Impacts		Adaptation benefits (% of impacts)
				Without adaptation	With adaptation	
Yates and Strzepek, 1998	GDFL (600ppm/2060) UKMO (640ppm/2060) GISSA (630ppm/2060)	Egypt	Extensive adaptation measures ¹	-4.25	2.85	167%
				-4.60	-0.70	115%
				0.50	4.50	800%
	GDFL (600ppm/2060) UKMO (640ppm/2060) GISSA (630ppm/2060)		Trade deficit changes	44.0	30.5	31%
				48.5	19.0	61%
				11.4	-5.7	150%
Reilly <i>et al.</i> , 2001	IS92a (HaDCM, CGCM) 2030	United States All crops Irrigated crops Grains rain-fed Fruits and vegetables Rain- fed	Changes in planting dates and cultivars	12.6	18.3	45%
				7.5	13.8	84%
				20.9	32.0	46%
				22.4	62.7	1%
	2090	All crops Irrigated crops Grains rain-fed Fruits and vegetables rain-fed		29.5	38.8	31%
				19.8	28.8	45%
				32.0	53.8	68%
				62.7	63.6	1%

Table 2.5. Quantified adaptation benefits in agriculture from selected studies (cont.)

Study	Climate scenario	Area	Adaptation	Impacts		Adaptation benefits (% of impacts)
				Without adaptation	With adaptation	
Adams <i>et al.</i> , 2003	High resolution RegCM (540ppmCO2)	United States	Changes in planting dates and cultivars	Yield changes		262% 26%
		Dry land crops Irrigated crops		4.3% 9.3%	15.4% 11.6%	
	Low resolution CSIRO (540ppmCO2)	Deterministic Stochastic ²		Welfare		1061% 229%
		United States		.32 -2.05	3.61 2.65	
Sluczyński <i>et al.</i> , 2000	GISS and GDFL (2xCO2)	Dry land crops Irrigated crops	Changes in cultivars, crop mix, and management practices	Yield changes		117.1% 23.2%
		Deterministic Stochastic		8.8% 8.6%	19% 10.6%	
				Welfare		87% 112%
		Poland		3.05 3.51	5.69 7.43	
				Change in agricultural production -5 to -25%		20-100%

1. Includes large shifts in planting dates (>1 month), increased fertiliser applications, and new investments in irrigation (as defined by adaptation level II in Rosenzweig and Parry, 1994).

2. The stochastic version of the model accounted for climate variability.

In particular, adaptation measures are projected to have very limited benefits in many African contexts. A study of Malian agriculture shows that on-farm adjustments in planting dates do not offer significant benefits in terms of offsetting yield impacts (Butt *et al.*, 2005). A study in The Gambia, meanwhile, presents a more nuanced picture (Njie *et al.*, 2006). For the period 2010-39 climate change is projected to increase millet yields slightly. However, this increase can be amplified significantly through adaptation measures. Specifically, fertiliser use could increase yields by 33% and irrigation by 37%. Over the longer term (the period 2060-90) millet yields could decline (by almost 300%) if precipitation were to decline during the cropping season. This would require significant investments in irrigation. A benefit-cost analysis was then performed, which concluded that irrigation would not be an economically viable option at the farm level.

The literature on the cost side of the adaptation equation for agriculture, meanwhile, is almost entirely lacking. As noted earlier, this is in part because the focus has been on farm level adjustments, which are shown to significantly offset climate change impacts on yield, while assumed to themselves cost very little. However, agricultural production is influenced significantly by public policies and there is a need to ensure that these interventions provide a conducive environment for adaptation at the farm level. This may include the provision of public goods (*e.g.* research on drought resistant crop varieties, climate forecasts).

One recent study estimates that the scale of such additional investment needs for agriculture, forestry and fisheries will be USD 14.23 billion per year by the year 2030 (McCarl, 2007). Specifically, three types of investments are costed: in research (*e.g.* in drought resistant seed varieties), agricultural extension, and physical capital (such as irrigation infrastructure). The levels of investments in each of these three categories for the year 2000 are projected to the year 2030 based on assumptions about their growth under business as usual (*i.e.* in the absence of climate change). Next, fairly *ad hoc* assumptions are made on what additional percent increments might be needed to these investments by the year 2030 in the light of climate change. For example, it is assumed that research expenditures would need to increase by an additional 10% to address climate change, without explicit discussion of the precise impacts that such research investments would seek to offset or how such a costing estimate was made. Likewise, the investments in physical capital are assumed to increase by 2% globally (and investments in agricultural extension by 10% in developing countries) to respond to climate change, again with very limited justification. The costs of adaptation, therefore, are not calculated independently. Rather, they follow directly from these assumed percentages of incremental investments which are then multiplied to very large baseline

investment flows. These shortcomings raise questions about the reliability of the results.

Water resources

Water supply will be affected by changes in temperature and shifts in precipitation patterns. The impacts of climate change on precipitation are quite uncertain and will differ significantly across regions. These changes will affect many sectors which depend on water supplies, including drinking water supplies, waste water treatment, and agriculture. Off stream uses, such as navigation and hydropower, will also be impacted. In addition, river water quality may also be affected due to lower streamflow, higher temperatures, and higher concentration of organic matter linked to more intense precipitation and erosion. Ecosystem health may be impacted by both poorer water quality and changes in flow regimes.

Adaptation in the water sector requires a combination of both supply and demand side measures. Supply side measures fall into two broad categories: (i) supply enhancement, by building new storage capacity, prospecting and extracting ground water, removing invasive species from water storage, rainwater harvesting and water transfers; and (ii) harnessing unviable water through desalinisation, wastewater reclamation and other measures. On the demand side, meanwhile, measures focus on reducing demand and promotion of more efficient water use through measures that include recycling, changing usage patterns, importing water-intensive products, increased use of rain-fed agriculture, greater use of water markets and other economic incentives.

While very limited, the literature on adaptation in the water sector covers a diversified set of impacts and adaptation measures. This section reviews the few studies looking at the costs and benefits of adaptation measures related to these impacts, followed by an evaluation of the only published costing of adaptation measures at the global level.

Regional and local cost/benefit estimates

Costs and benefits have been assessed for adaptation measures that offset the impacts of climate change on water availability, reliability of water supplies, as well as on water quality. In the United States, Kirshen *et al.* (2006) assessed the reliabilities of local and regional water supply systems in metropolitan Boston under climate change. To assess supply reliability, the authors derived water demand from projections of population and economic growth. These were then used in conjunction with water supply scenarios as determined by climate change impacts on precipitation

and evapo-transpiration. Under the baseline scenario of no adaptation to climate change, it was found that the reliability of local water supply systems would decline from 100% currently to less than 80% by 2100. These declines, however, could be offset (modestly) by demand side management, while connecting local systems to the main regional water system could significantly boost the reliability to almost 100%. The costs of these measures were not evaluated. The same study, however, does examine the costs of adaptation measures to maintain water quality in the Assabet River near Boston. Here climate change primarily impacts water quality through increases in nonpoint source pollution and stream temperatures and lower low flows. The adaptation strategies studied included the additional cost related to extra treatment of wastewater in order to reduce the input of nutrients in the river and also the establishment of wetlands and infiltration basins to reduce non-point source inputs. Results indicate that climate change and population increase would lead to USD 30-39 million in capital cost and USD 300 000 to USD 600 000 in annual operating costs to maintain aquatic communities in the Assabet River. Without these changes, capital costs to meet water quality goals would be USD 22.5 million with operating costs of USD 210 000. Most of the changes are due to climate change as most of the region is close to full development.

Some estimates are also provided for adaptation costs related to water utilities in Canada. Dore and Burton (2001) looked at adaptation costs in response to impacts of climate change on the availability of drinking water supply and the capacity of treating wastewater. Water utilities are expected to be affected by climate change since the timing and regional patterns of precipitation may change. As precipitation is projected to increase in many regions, drinking water supply is not likely to be affected by climate change. However, many regions will face adaptation costs as rainfall increases beyond existing capacities for wastewater treatment and storage and, thus, such capacities will need to be expanded. The authors considered potential adaptation strategies, such as building new treatment plants, improved efficiency of actual plants, or increases in retention tanks. Results indicated that adaptation costs for Toronto could be as high as CAD 9 400 million if extreme events are considered.

A different approach was taken by Muller (2007) who estimated the costs of adapting urban water infrastructure in (Sub-Saharan) Africa to climate change to be USD 2-5 billion annually. This study relies on three assumptions: (i) reliable yields from dams will reduce at the same rate as stream flow: a 30% reduction in average stream flow will result in a 30% reduction in yield and the unit cost of water will increase by more than 40%; (ii) where waste is disposed into a stream if stream flow is reduced by 30%, the pollutant load must be reduced by 30% and as treatment costs to achieve

lower pollution levels increase rapidly overall cost of wastewater treatment could double; and (iii) power generation reduces linearly with stream flow: a 30% reduction in stream flow will result in a 30% reduction in electricity production.³ The cost estimates in this study were divided into costs of adapting existing water infrastructure, which ranged from USD 1 050 million to USD 2 650 million, and costs of new developments, which were estimated to rise by between USD 990 million and USD 2 550 million.⁴

At a more local level, Callaway *et al.* (2006) provide estimates of water management adaptation costs and benefits for the Berg River basin in South Africa. Adaptation measures investigated include the establishment of an efficient water market and an increase in water storage capacity through the construction of a dam. Accounting for climate change impacts on urban and farm demand, they provided cost and benefit estimates for storage and water market adaptation strategies. The discounted impact of climate change over the next 30 years was estimated to vary between ZAR 13.5 billion and ZAR 27.7 billion. The net welfare benefits of adapting water storage capacity under current allocation rights were estimated at about ZAR 0.2 billion, while adding water storage capacity in presence of efficient water markets would yield adaptation benefits between ZAR 5.8 billion and ZAR 7 billion. The authors assessed the robustness of adaptation responses and showed that under efficient water markets, the costs of not adapting to climate change that does occur outweigh the costs of adapting to climate change that does not occur.

Climate change is likely to lead to rapid glacier retreat, which will disrupt the water cycle in the many glacier-dependent basins, such as in the Andes, and thus affect water regulation and availability.

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3. The study uses unit costs derived from project experience to calculate the costs of adapting existing urban water infrastructure. For the costs of new developments, the study assumes that the costs of adapting to climate change for new developments will be similar to those for existing systems.
 4. Breakdown of costs to adapt existing urban water infrastructure: USD 500-1 500 million capital costs for urban water storage (USD 50-150 million annual equivalent); USD 100-200 million annually for wastewater treatment; and USD 900-2 300 million annually for electricity generation. Breakdown of costs for new developments: USD 150-500 million capital costs for urban water storage (USD 15-50 million annual equivalent); USD 75-200 million annually for wastewater treatment assuming an additional 100 million people served; USD 900-2 300 million annually for electricity generation assuming installed capacity doubles.

Vergara *et al.* (2007) estimated potential adaptation costs to climate change for Quito, Ecuador. The authors suggest that the city will have to divert additional water and build new water infrastructure at an accelerated pace in order to cope with a reduction in water yields and supply from existing water sources due to glacier retreat. They estimated the incremental net present value of the accelerated investments required for the next 20 years to be around USD 100 million. This represents a 30% increase over the infrastructure required under the “no climate change” scenario.

Finally, climate change will also affect the management of river floods, through increases in precipitation and extreme events, which are likely to alter river discharges. A case study examining the impact of climate change on river flood management for the river Rhine was carried out by the European Environment Agency (EEA, 2007). Climate change is expected to have a significant effect on peak discharges of certain European rivers, such as the Rhine. Policies designed to manage river floods need to take into account not only the long-term natural and socio-economic developments but also the risks presented by climate change. The EEA study concluded that adaptation could reduce most of the climate change induced increases in river flooding risks at relatively modest costs. Optimal flood defence investments were estimated to cost around EUR 1.5 billion and to lead to significant benefits by reducing climate-induced flood damage from EUR 39.9 billion to EUR 1.1 billion over the 21st century.

Overall, the literature on adapting water supply and demand in response to the impacts of climate change at the regional level is still too sparse and context specific to make a broad assessment with regard to the costs. Nevertheless, some messages do emerge from this limited literature. For regions where precipitation is expected to increase, issues such as flood management and waste water treatment may become problematic and impose substantial additional costs. On the other hand, in regions where precipitation will decline or where water availability might decline on account of glacier retreat, investments in enhanced storage, as well as enhancing the efficiency of water allocation becomes highly valuable. However, drawbacks in terms of market access for urban poor and related social impacts may need to be investigated. To ensure supplies of drinking water, a diversification of supply sources through the interconnection of supply systems can also prove to be beneficial. Maintaining river water quality may also be very costly for public authorities.

Global costs

There is only one assessment of the costs of adaptation in water resources at the global level (Kirshen, 2007). This study estimates the global

costs of adaptation associated with additional water infrastructure needed by 2030,⁵ given present and future total projected water demands for four sectors (urban domestic/commercial, irrigation, rural domestic and industrial), and water supplies in more than 200 countries. Four main water production utilities are costed: additional surface storage reservoirs and ground water wells to supplement existing reservoirs and wells, as well as desalination plants and water reclamation technologies in case of “water shortages”. The study compares future projected water demands from different sectors to water supplies. Next, the need for additional production infrastructure is determined, based on an assumed international legislation that would limit 2050 water withdrawals to 40% of 2050 total available national water resources.⁶ If one country has water withdrawal requirements that are largely covered by its internal water availability (and therefore is in line with the mentioned legislation), the additional reservoir storage and wells needed are determined and costed. It is assumed that water demands have to be covered in the following order of priority: domestic/commercial, industrial and agricultural irrigation needs. If instead, one nation cannot meet the international legislation because it faces “water shortage”, *i.e.* withdrawal requirements exceed 40% of its mean annual flows (MAF), it has to resort (in order of priority) to desalination for domestic/commercial and to reclaimed water for irrigation needs. Implementation costs of these technologies are then evaluated and added to additional storage and wells required. Even using all these sources, some nations will still face water shortages and will have to rely upon virtual water to meet their needs.

The overall conclusion of this assessment is that adaptation costs in the water sector will amount to a total of about USD 531 billion for the period up to 2030. However, these costs include adaptation responses to both economic and climatic changes. The costs of adaptation to climate change alone are not isolated from other investments needed. While USD 80 billion, equivalent to 15% of total adaptation costs, are estimated to be needed in

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5. The analysis period is 2030, but since water resource investments are typically made at least for 20 years in the future, the planning period is 2050. This assumes that nations are willing to plan ahead for climate change. Therefore, national water supply and demand estimates were obtained for 2050.
 6. This study assumes that there will be an international requirement that in-stream flows must be at least 60% of mean annual flows (MAF), as presently many watersheds are over abstracted. This means that a maximum of 40% of MAF can be used for water withdrawals (off-stream use). The MAF is that of a nation’s available water resources, which includes its internally generated water resources as well as reasonable upstream releases of surface water from countries with excess water.

North America and Europe jointly, USD 451 billion (85%) are estimated to be required in developing countries, mainly Asia and Africa.

The assessment by Kirshen (2007) was subsequently modified and published in UNFCCC (2007), which reports the total global adaptation costs to be USD 898 billion for the period up to 2030. These updated costs consider two factors which had not been costed in the Kirshen (2007) study: (i) the increase in reservoir and groundwater costs as the best located sites are developed; and (ii) unmet irrigation demands. The UNFCCC update also reports the costs of adapting specifically to climate change as 25% of the total costs, *i.e.* USD 225 billion for the period up to 2030, equivalent to approximately USD 11 billion per year (UNFCCC, 2007).

While the analytical approach in this assessment is fairly detailed, there are nevertheless some key limitations. First, the cost estimates do not include operation and maintenance costs. Second, the empirical numbers on costs of specific measures are typically taken from specific examples from the United States before being scaled up to various regions based upon the regional differences of costs.⁷ Third, and perhaps most importantly, although the study accounts for improvement in water-use efficiency the study only costs supply side adaptation options (such as investments in new storage) without explicitly estimating the costs of demand side measures, such as promotion of indigenous practices for sustainable water use, increased use of rain-fed agriculture or expanded use of water markets and other economic incentives. Inclusion of such demand side measures could significantly lower the adaptation costs.

Energy demand

The literature on adaptation costs in the energy sector is limited to the costs associated with increases in energy demand for cooling in the summer and reduced heating in the winter. In terms of geographical coverage the literature is largely limited to the United States. The cooling demand (which will increase) is met entirely by electricity, while the offset due to reduced heating demand in the winter will be distributed amongst multiple energy sources. Whether there will be net adaptation costs or benefits is also dependent upon assumptions that are made about the future evolution of building stocks.

Rosenthal *et al.* (1995) used an engineering “bottom-up” model and found net benefits, that is a net reduction in energy consumption, of

7. While all costs were scaled, the scale factor used was only taken from irrigation data, as this data was readily available.

5.3 billion (1990 USD), for the US economy under the assumption of a one degree temperature rise by 2010. Meanwhile, Morrison and Mendelsohn (1999) used a “top-down” approach, and looked at the climate change impacts on US energy demand, disaggregating by sectors and fuel/energy types. The authors report net adaptation costs (*i.e.* increased energy expenditures) ranging from 1.93 billion (1990 USD) to 12.79 billion (1990 USD) for the 2060 horizon. The difference between these results and the net benefits computed by Rosenthal *et al.* (1995) is partly explained by the different time horizons considered in the two studies, and partly because the bottom-up study had more optimistic assumptions about the potential for energy savings.

The estimates of the net adaptation costs or benefits in energy demands are also sensitive to the assumptions that are made about the future evolution of building stocks. Morrison and Mendelsohn (1999) and Mendelsohn (2003) differentiated between scenarios with and without changes in climate sensitive building characteristics.⁸ The two studies conclude that including evolution in building characteristics significantly increases the cost of adaptation, as future buildings will have greater cooling capacity. For the 2060 time horizon, the studies estimate that changes in building stocks and characteristics raised the cost of adaptation by 2.98 billion (1990 USD) to 8.57 billion (1990 USD) depending on the underlying economic scenario. Sailor and Pavlova (2003) reach similar conclusions. For the city of Buffalo (United States) the authors report that up to two-thirds of estimated energy consumption rise was induced by the growth in the cooling market. A more recent study, by Mansur *et al.* (2005) examines the impact of climate change not only on energy demand, but also on the choices between energy types. The authors conclude that climate change leads towards a shift in favour of electricity consumption relative to other energy sources since it is the primary source of cooling energy. Taking this shift in energy mix into account, the authors estimate a net increase in US energy expenditures ranging from 4-9 billion (1990 USD) for 2050 and from 16-39.8 billion (1990 USD) for 2100, depending on the severity of climate change.

A few general conclusions can be drawn from the literature on energy costs. First, at least for the United States, the majority of studies conclude that the adaptation costs of increased cooling will be greater than the

8. Morrison and Mendelsohn (1999, p. 218), included climate sensitive building characteristics such as “building material, conservation efforts, the choice of heating and cooling equipment, and energy-consuming appliances as well as some aspects of building structure such as the number of rooms, doors, and windows.”

benefits associated with reduced heating demands. Second, the studies are yet to systematically assess the effects of changes in climate variability, and also how market forces might mediate the shifts in energy demand through changes in prices. Finally, the trade-offs between increased cooling versus reduced heating will be different for other regions and countries. With the exception of Cartalis *et al.* (2001) who provided estimates for the southeast Mediterranean region, assessments of the adaptation costs in the energy sector outside of the United States are scarce. One recent study, however, has examined the investment costs that might be needed in additional energy generation capacity to meet the additional demand for air conditioning in the Paris region (Hallegatte *et al.*, 2007). New work is also currently underway to examine the effects of hotter summers and milder winters on a global basis but there are no empirical estimates yet on the costs of adaptation (Di Cian *et al.*, 2007).

Other sectors: infrastructure, tourism and public health

Beyond coastal zones, agriculture, water resources, and energy demand that have been reviewed in preceding sections, there are only three areas where a few isolated estimates exist for adaptation costs and benefits. These are infrastructure, (winter) tourism, and public health.

Infrastructure

Infrastructure is part of the adaptation solution in many climate sensitive sectors. It is also a high value asset which is particularly vulnerable to climate change on account of its long lifetime, over which climate change impacts will become progressively more pronounced. Adaptation costs for infrastructure, therefore, could have two interlinked but different meanings: (i) the costs of infrastructural solutions that serve as adaptations in many climate sensitive sectors or regions; and (ii) the costs of “climate-proofing” infrastructure itself to the impacts of climate change. With regard to the former perspective, many of the cost estimates for adaptation in coastal zones, water resources, energy, and (to some extent) agriculture are, in fact, infrastructure costs. This includes costs of protective structures in coastal zones, storage or irrigation infrastructure for agriculture and water supply, as well as energy supply infrastructure – that have been discussed already.

Taking the latter perspective, meanwhile, there are some cost estimates that are available for specific local contexts – for example the costs of building the Confederation Bridge in Canada one metre higher than currently anticipated to accommodate sea level rise, or raising the sewage treatment facility on deer island in the Boston harbour, again to take sea

level rise into account (IPCC, 2007b, Chapter 17). In such cases, the precise cost numbers, while extremely relevant from a project planning perspective, do not really offer any insights that might be of broader policy relevance.

Beyond that, only very few studies exist which have attempted to provide more aggregate information. One study, for Canada, costs two infrastructure related adaptations: the replacement of the Canadian winter/ice road network by “all weather roads” in response to rising temperatures; and investment in enhanced rainwater storage and wastewater treatment facilities (Dore and Burton, 2001). The total costs of these measures are estimated to be in the range of CAD 3.5-12 billion for the year 2100. A more recent study examines the cost of adapting public infrastructure in Alaska to five impacts associated with climate change: permafrost melt, sea level rise, accelerated coastal erosion, increased flooding, and increased fire risk. The study estimates that the repair and replacement cost for 16 000 pieces of public infrastructure in Alaska to adapt to these impacts by the year 2030 will be as much as USD 6.1 billion, which is a 20% increase from baseline investment levels (Larsen *et al.*, 2007). In contrast to these two bottom-up studies, which aggregate micro-level data, the third study is more top-down and estimates the worldwide costs of adapting infrastructure to range from USD 7.8-130 billion by the year 2030 (Satterthwaite, 2007).

(Winter) tourism

Studies investigating costs of adaptation to climate change in the tourism sector have mainly focused on winter tourism and the ski industry. Winter tourism is likely to be most hit, as it could become effectively impracticable in some regions. Agrawala (2007) and Bosello *et al.* (2007) assess adaptation measures in the winter tourism sector/industry and some of the costs provided for technological adaptations. The range of adaptation practices found among ski area operators can be divided into two main categories: technological and behavioural. Technological adaptations appear so far to be the main types of adaptation strategies adopted by tourism stakeholders in the European Alps. There are four main types of technological adaptations: landscaping and slope development; a move to higher altitudes and north facing slopes; glacier skiing; and artificial snow making. Behavioural adaptations range from operational practices and financial tools to new business models and a move towards the diversification of activities. Few cost estimates exist, but there are *ad hoc* numbers for some technological adaptations, especially for artificial snow making. Costs for behavioural adaptations are not provided, as these measures are complex and difficult to cost.

While some adaptation strategies, such as the protection of glaciers with white sheets, can be relatively cheap (cost of EUR 3/m²), other strategies, such as extending ski areas to high elevations and artificial snow-making, can be expensive. For example, Mathis *et al.* (2003), who carried out a survey of projected ski area developments in Switzerland, found that the high mountain extensions would cost between EUR 25-30 million. In France, for the 2003-04 winter season, investment costs for snow-making material reached EUR 60 million. However, the investment in new snow-making equipment rarely represents the development of completely new installations but an extension to or improvement in current equipment. Operational costs for that same season in France reached EUR 9.4 million.

Costs of snow making are divided into investment costs, operational costs and maintenance costs. Different figures are available with regards to the production of one cubic metre of snow. For example, the Association of Austrian Cableways estimates the costs to be between EUR 1-5, while another study estimates the costs to be between EUR 3-5 per cubic metre (CIPRA, 2004). This latter study also estimates that it costs on average EUR 136 000 to cover one hectare with artificial snow. The annual operating costs in Switzerland vary between EUR 19 000 and 32 000 per kilometre. For example, in the canton of Valais/Wallis in Switzerland the operational costs of a snow-making system were estimated at EUR 33 000 per kilometre. However, there is only a small difference of about EUR 2 000 between normal and snow-deficient winters.

However, these adaptations are not necessarily sustainable in the long term and may also generate negative externalities. For example, glacier skiing may not be sustainable, as it is estimated that by 2050 about 75% of glaciers in the Swiss Alps will have disappeared and that by 2100 the whole of the Alps could lose almost their entire glacier cover. Other adaptations are likely to have detrimental environmental impacts. Interventions of bulldozers and excavators, the installation of ski transportation facilities, the implantation of artificial snow pumps and increase in artificial snow making can be very destructive on the environment, lead to “scars” on the Alpine landscape, impact water supplies, and increase energy consumption with consequent impact on greenhouse gas emissions (Abegg *et al.*, 2007). These environmental externalities have not been considered in the costing studies, and their inclusion may increase costs significantly.

Public health

While there is extensive literature on the implications of climate change on public health⁹ on the one hand and on the costs and benefits of delivering health services on the other, specific information on adaptation costs and benefits in this sector is still embryonic. Only one study provides global adaptation costs to climate change in the health sector (Ebi, 2007). It estimates direct adaptation costs in a bottom-up approach by investigating treatment costs of additional number of cases limited to three health outcomes: diarrhoeal diseases, malnutrition and malaria. Globally, the study estimates these costs to amount to a total of USD 4-5 billion by 2030,¹⁰ primarily in developing countries.¹¹ The study also presents a high cost estimate of USD 11-12.6 billion although no further explanation is provided.

While the above mentioned study explicitly isolates adaptation costs induced by climate change it does have some important limitations. It does not, for example, include costs of setting up new infrastructure needed, which may be important especially in developing countries.

More generally, costing the component of investments in public health infrastructure that might be needed to address climate change as opposed to those required on account of social and demographic trends is not straightforward. Further, the boundary between what constitutes climate change impacts and what might be an adaptation is not entirely clear in the case of public health. Specifically, the costs of treatment of climate sensitive diseases could equally be included under the impacts of climate change and

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9. See for example, the PESETA Project co-ordinated by the Institute for Prospective Technological Studies, one of the European Commission's Joint Research Centres, <http://peseta.jrc.es/index.html>.
 10. To provide these numbers, first, year 2002 current annual incidences of diarrhoeal disease, malnutrition and malaria are taken from the World Health Organization (WHO) for 14 sub-regions of the world. Climate-change-related health outcomes were then isolated from health outcomes due to other factors using relative risk associated with climate change by 2030. Assuming that current incidence cases would remain constant by 2030, these were multiplied by the climate change risk factors to yield additional incidence cases of each health outcome due to climate change. Finally, additional incidence cases are multiplied by the unit cost required by each disease treatment.
 11. All malnutrition and malaria cases are assumed to concern developing countries only. Developed countries are affected by 1-5% of the diarrhoeal disease cases, which would amount to total adaptation costs of USD 22-111 million (UNFCCC, 2007).

under costs of (reactive) adaptation. What assumptions are made would therefore critically affect the final estimates of adaptation costs and benefits.

Multi-sectoral estimates at the national level

While sectoral assessments of adaptation costs and benefits have the advantage of offering greater insight into the adaptation process, they might only be of limited relevance to planners at the macro level who might need more information on more aggregate “price tags” for adapting to climate change. This is a rapidly developing area of analysis on two fronts: at the national level, where a number of Least Developed Countries (LDCs) have produced cost estimates of priority adaptation actions; and at the global level, where international agencies have produced estimates of the global costs of adaptation. This section evaluates the emerging results from the national level multi-sectoral estimates of adaptation costs. The global results are evaluated in the next section.

At the national level, a number of costings of adaptation needs have recently been undertaken through a stakeholder driven process as part of the National Adaptation Programmes of Action (NAPAs). NAPAs are being prepared by the LDCs under the United Nations Framework Convention on Climate Change (UNFCCC) in order to identify priority activities, which address their urgent and immediate needs with regard to adaptation to climate change. They are developed based on a bottom-up process, which gives prominence to community-level input as an important source of information. The development of NAPAs is based on the recognition that LDCs have a limited ability to adapt to the adverse effects of climate change. In order to address the urgent adaptation needs of LDCs, NAPAs follow an approach that focuses on enhancing adaptive capacity to current climate variability and extremes, as this will in turn help address the adverse effects of climate change. A key output required from the NAPAs is a list of priority adaptation activities, whose further delay could lead to increased vulnerability or increased costs at a later stage. The analysis of costs in the following sections covers the 23 NAPAs that had been submitted by end 2007.¹²

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12. Bangladesh, Bhutan, Burundi, Cambodia, Comoros, Democratic Republic of Congo, Djibouti, Eritrea, Guinea, Haiti, Kiribati, Lesotho, Madagascar, Malawi, Mauritania, Niger, Rwanda, Samoa, Senegal, Sudan, Tuvalu, Tanzania, Zambia. Cost information is reported in all NAPAs except that of Niger.

Cost estimates of priority projects

Clearly there are a number of elements to both the NAPA process and the final output. Many of these elements have been reviewed elsewhere (see for example Osman-Elasha and Downing, 2007). The focus here is on the information on the costs of priority adaptations, which the NAPAs are required to report. For the purposes of this analysis, the priority projects that are costed have been broken down into eight categories: agriculture, water, extreme events, coastal zones, health, infrastructure, ecosystems, and cross-sectoral measures (Box 2.1).

Box 2.1. Description of the eight sectors/categories chosen

Agriculture

This includes projects relating to food security, irrigation, crop and livestock production, agro forestry and to a lesser extent aquaculture and fisheries. Projects addressing soil erosion and reforestation activities in order to increase soil productivity were also included.

Water

This includes projects that address water supply and sanitation problems; promote integrated water resource management (IWRM); improve water use efficiency and water storage; reduce pressure on water resources; develop water infrastructure, drainage, rainwater harvesting techniques and water treatment and desalinisation techniques for coastal areas; and provide better access to water resources to sedentary and pastoral populations.

Extreme events

This includes projects which involve developing early warning systems, constructing dykes to address flooding issues and measures aiming to strengthen community disaster preparedness and response capacity.

Coastal zones

This sector includes projects that aim to protect coastal zones through the construction and upgrading of coastal defences and causeways, development of an integrated management of coastal zones and plantation of mangroves.

Health

This includes projects that aim to increase awareness of diseases, such as malaria, improve medical facilities and the control of vector borne diseases (*e.g.* spraying vector breeding areas), especially in rural areas, and improve water quality and sanitation facilities in order to reduce the extent of water borne diseases.

Infrastructure

This sector includes projects that aim to extend communication and telecommunication infrastructures, enhance stability of buildings and impose construction norms to address potential impacts of extreme events.

Cross-sectoral

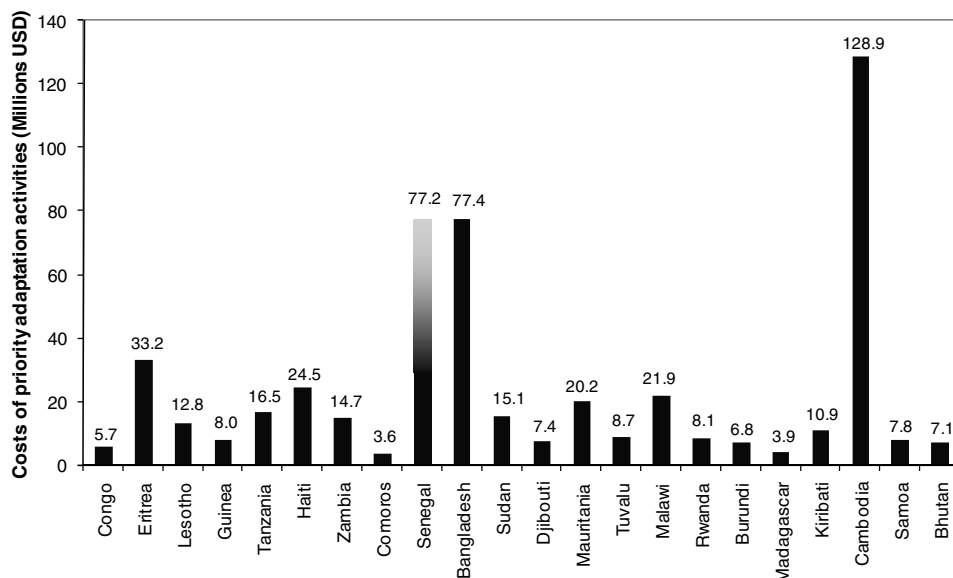
This includes projects that are broadly defined and/or have multi sectoral objectives and benefits. An example of such a project is one that aims to increase crop productivity, improve water quality and reduce health risks.

Ecosystems

This includes projects to protect natural resources, such as coral reefs and forests, in order to maintain natural habitats and biodiversity.

The total costs of all priority projects identified in the 22 NAPAs amount to approximately USD 472 million. While nearly all projects only report point estimates of costs, one coastal zone project in Senegal reports costs ranging from USD 16-64 million. If the upper end of this range is considered, then the total costs of all priority projects in the 22 NAPAs would be USD 520.2 million. The highest national costs of priority projects has been identified in Cambodia (USD 128.9 million), followed by Bangladesh and Senegal (USD 77.4 million and USD 77.2 million respectively). Most NAPAs, however, report cost estimates between USD 5-20 million, as shown in Figure 2.2.

Figure 2.2. Summary of total costs for priority adaptation activities identified in NAPAs

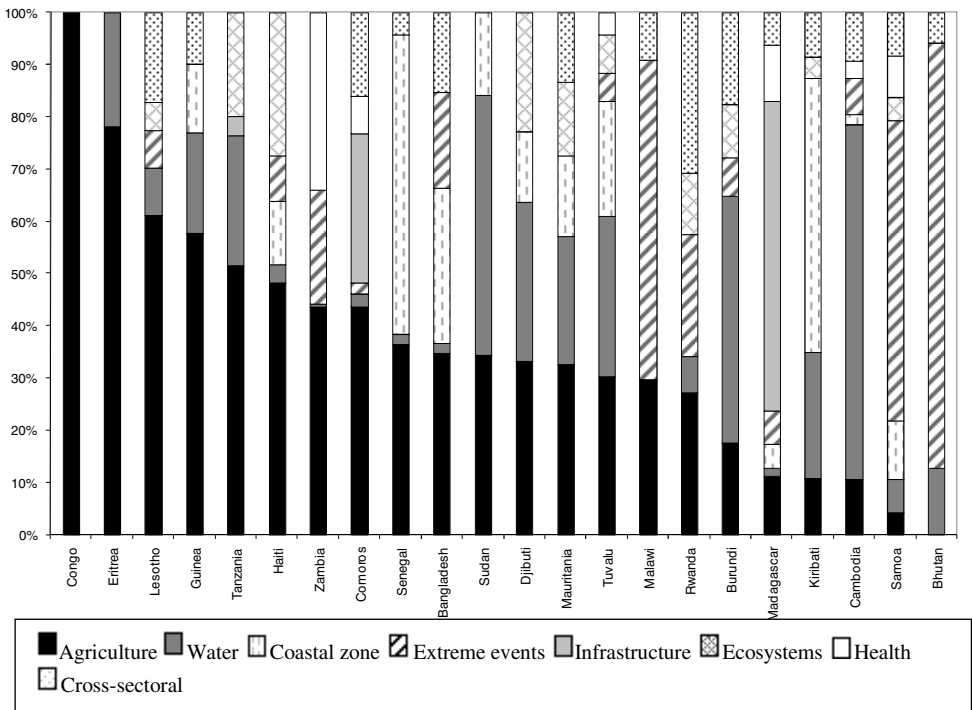


Further insights can be obtained by examining the breakdown of adaptation costs, according to the sectoral classification described in Box 2.1. These results are presented in Figure 2.3.¹³ The highest costs are in agriculture for a majority of the countries. For 14 of the 22 countries that have submitted NAPAs, adaptation costs in the agricultural sector represent at least 30% of the total adaptation costs. Another priority sector is water, and together agriculture and water account for approximately 60% of total adaptation costs identified in the NAPAs. Many countries also ascribe high costs with regard to priority projects to deal with extreme events, with these costs constituting over half of the total costs of priority projects for countries like Samoa and Malawi. At the level of individual projects, meanwhile,

13. Since the presentations/descriptions of projects and the definition of project costs vary from country to country, it had to be assumed that project costs, funds or budgets estimated represent total project costs. In addition only a few countries identify which sector each project is attributed to, in other cases the projects were classified into particular categories based on the subjective judgment of the authors. Yet, a certain amount of uncertainty is still associated with this classification, as certain projects could fall into one or more sectors. The difficulty in defining clear sectoral boundaries for each project may have significant impacts on total sectoral costs and the relative weight of each sector in total cost estimates.

costs range from USD 32 500 for a project in Madagascar aiming to restore coastal habitats to USD 45 million for a project in Cambodia aiming to enhance food security by increasing water availability and reducing risk of crop failures.

Figure 2.3. Distribution of adaptation costs by sector for each country



Discussion

Despite their diverse geophysical and social contexts, the countries that have developed NAPAs identify many common adaptation priorities. These include general capacity building and awareness raising, studies to establish baselines for climate change impacts and adaptation, improved dissemination of information, such as disaster early warning, that could facilitate adaptation, developing alternatives to activities that might be particularly vulnerable to climate change, upgrading existing infrastructure such as civil defences, as well as developing new infrastructure, for example water reservoirs (Njie, 2008).

In principle, a potential strength of the NAPAs is that they are based on concrete project proposals and activities developed during a process

adopting a bottom-up approach and engaging a wide variety of stakeholders. The adaptation priorities and projects should, therefore, be more realistic and better reflect priorities on the ground than the stylised abstract assumptions of adaptation that are embedded in top-down studies. Indeed, a reading of the NAPAs reveals many “atypical” adaptation priorities that can only be identified through stakeholder driven processes. For example, the NAPA of Comoros highlights as one of the priority projects “Short conservation of fish under ice to reduce losses after catches, due to high temperature”. The project is justified by the deterioration and reduction of catches due to temperature increase and the lack of conservation techniques. These may affect the fish market as well as ill health incidences of diarrhoeal diseases due to consumption of rotting fish. Such adaptation priorities would be typically overlooked in more theoretical analyses.

One striking contrast between the sectoral estimates reviewed earlier and the NAPAs is the high cost ascribed to priority adaptations in agriculture. By contrast, most modelling studies in agriculture conclude (or assume) that significant yield benefits can be obtained from adaptation measures that will cost very little. The priority actions identified in the NAPAs concentrate mainly on rural livelihoods and how to adapt the livelihoods of rural farmers relying on agriculture. In addition, NAPAs identify several activities relating to soil erosion reduction and improving soil fertility. These activities differ considerably from those identified in the theoretical farm level studies described earlier in the sectoral section. This may suggest that farm level modelling studies may only be looking at adaptation in the agricultural sector from a narrow perspective. Adaptation in the agricultural sector for rural households will not simply be about small adjustments and better adapted crop varieties but will require wider changes in the economy and diversification of their livelihoods. These changes will require financial support from governments. Soil erosion, soil fertility and natural resource management measures to adapt the agricultural sector will also require significant financial outlay.

There are clearly important strengths to the NAPA process and the insights they reveal about adaptation needs. However, with regard to the specific issue of adaptation costs, there are considerable limitations to the information presented in the NAPAs. This is because generally no justification or sourcing of underlying analyses of the cost estimates is provided within these documents. For example, 9¹⁴ of the 22 NAPAs do not provide any explanation for total project costs given. In other cases, the

14. Bangladesh, Cambodia, Comoros, Haiti, Kiribati, Guinea, Mauritania, Rwanda and Zambia.

NAPAs only note that costs are based on historical and/or ongoing projects, but the underlying analysis is not available. In addition there are a number of factors that can also result in the under- or over-estimation of adaptation costs in the NAPAs. These include, simplified assumptions regarding the geographical distribution of project input prices and omission or inadequate consideration of the costs of contingencies as well as the delay in implementation (Njie, 2008). Therefore, while such estimates might be indicative of relative priorities placed by stakeholders, they may not necessarily be a reliable guide to the actual costs of implementing such measures.

Global multi-sectoral estimates

Following a long period of total absence of any empirical estimates of the global costs of adaptation across multiple sectors, there have been six assessments which have explicitly confronted this issue within the short period of one year between mid-2006 and late 2007.

Multiple factors have contributed to this growing interest in the global costs of adaptation. First, such estimates can serve an agenda setting role and help raise the profile of adaptation. Second, they can serve as a guide to international donors seeking to enhance the climate resilience (or “climate-proof”) of development projects and activities. Finally, they can help shape the discussion on financing adaptation needs in developing countries within the context of the international climate change negotiations.

In chronological sequence they include the Investment Framework for Clean Energy and Development of the World Bank, the Stern Review, the Intergovernmental Panel for Climate Change (IPCC) Working Group II Fourth Assessment Report, studies on adaptation financing by the Oxfam and the UNFCCC, and the UNDP Human Development Report. All, with the exception of the IPCC, provide specific numerical estimates for the costs of adaptation (Table 2.6).

Table 2.6. Estimates of costs of adaptation on a global scale

Assessment	Cost of adaptation	Time frame	Countries included	Sectors	Comments on methods/sources
World Bank (2006)	USD 9-41 billion per year	Present	Developing countries	Unspecified (presumably all sectors where ODA, FDI, and GDI are directed)	Estimate based on OECD and World Bank (WB) analyses of official flows exposed to climate risk. Costs of "climate-proofing" are assumed in the analysis.
Stern Review (2006)	USD 4-37 billion per year	Present	Developing countries	Unspecified (presumably all sectors where ODA, FDI, and GDI are directed)	Update, with slight modifications, of WB study.
Oxfam (2007)	At least USD 50 billion per year	Present	Developing countries	Unspecified (presumably all sectors where ODA, FDI, GDI, and NGO interventions are directed)	WB study, plus extrapolation of cost estimates from NAPAs and NGO projects.
UNDP (2007)	USD 86-109 billion per year	2015	Developing countries	Unspecified (presumably all sectors where ODA, FDI, and GDI are directed)	WB study, plus costing of targets for adapting poverty reduction programmes and strengthening disaster response systems

Table 2.6. Estimates of costs of adaptation on a global scale (cont.)

Assessment	Cost of adaptation	Time frame	Countries included	Sectors	Comments on methods/sources
UNFCCC (2007)	USD 28–67 billion per year	2030	Developing countries	Agriculture, forestry and fisheries; water supply; human health; coastal zones; infrastructure	In-depth costing of specific adaptations in water, health and coastal zones. Less detailed costing for agriculture, infrastructure, and ecosystems. Infrastructure more abstract.
UNFCCC (2007)	USD 44–166 billion per year	2030	Global	Agriculture, forestry and fisheries; water supply; human health; coastal zones; infrastructure	Infrastructure adaptation costs overlap with costing in coastal zones and water resources.

Even though five different studies have reported on the costs of adaptation at the global level, there are only two quasi-independent estimates. The first estimate is by the World Bank as part of the “Investment Framework for Clean Energy and Development” (2006), which was modified subsequently in the Stern Review (2006) and also served as the principal input to the assessments by Oxfam (2007) and the UNDP (2007). The second estimate is by the UNFCCC as part of its “Analysis of Existing and Planned Investment and Financial Flows Relevant to the Development of Effective and Appropriate International Response to Climate Change” (2007).¹⁵ As such, most of the cost estimates are linked to each other, rather than fully independent. Further, there has been a trend towards escalation of adaptation costs with successive estimates.

The World Bank (2006) and derivative assessments of adaptation costs

The World Bank study looks at the current magnitudes of three sets of financial flows in developing countries: Official Development Assistance (ODA) and concessional finance, estimated at USD 100 billion per year; Foreign Direct Investment (FDI), estimated at USD 160 billion per year; and Gross Domestic Investment (GDI), estimated at USD 1 500 billion per year.

In this study, 40% of ODA, 10 % of FDI and 2-10% of GDI are taken to be “climate sensitive”. The climate exposure of ODA draws upon previous studies by the World Bank and the OECD.¹⁶ The climate exposure of FDI and GDI, meanwhile, has been assumed and is not sourced to any underlying analyses. This is particularly critical, as the sheer magnitude of GDI (USD 1 500 billion per year, or 15 times the ODA) dwarfs other investments. Hence any modification on how much of GDI is exposed to

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15. While the UNFCCC cost estimates for other sectors largely follow an independent approach, its estimation of the adaptation costs for infrastructure does draw upon the cost assumptions made in the World Bank analysis.
 16. The climate sensitivity of ODA draws in part on the analysis conducted by the OECD which concluded that anywhere from 12-26% to 50-65% of official flows in Bangladesh, Egypt, Tanzania, Uruguay, Nepal, and Fiji could be potentially affected by climate risks. The OECD analysis, however, is only for these six countries, and scaling up to all ODA recipients is problematic. Further, being “climate sensitive” under this very broad definition does not automatically imply that investments would be required for adaptation. As the OECD report cautions “if an activity falls within the climate sensitive cluster that does not necessarily mean that it needs to be redesigned in the light of climate change” (van Aalst and Agrawala, 2005, p. 66).

climate risks would significantly alter the final estimate of total costs of adaptation. Next, the costs of “climate-proofing” these exposed investments are assumed to be between 10-20% of the financial exposure in each of these cases. Any change in these assumptions would significantly alter the overall costs of adaptation. This then yields the range of USD 9-41 billion per year for adaptation costs. The study does not quantify the benefits (in terms of reduced damages) of the adaptation investments.

The Stern Review (2006) does not develop new estimates of adaptation costs, but it does provide an update of the World Bank estimates. Following the same methodology, the Stern Review assumes that 20% of ODA, 10% of FDI, and 2-10% of GDI are climate sensitive. Likewise, with regard to costs, while the World Bank Investment Framework assumed that adaptation would cost 10-20% of the financial exposure, this range is updated to be between 5-20% in the Stern Review. These assumptions consequently yield a range of USD 4–37 billion per year for adaptation costs. The Review does not discuss the basis of the percentages chosen for the exposure of different financial flows to climate risks. There is also no discussion of the assumptions underlying the estimate that adaptation investments would cost between 5-20% of financial flows exposed to climate risks.

The adaptation cost numbers in the World Bank Investment Framework also serve as the primary input for the costing assessment by Oxfam (2007). In addition, the Oxfam assessment adds three elements: scaled-up costs of community level projects by non-governmental organisations (NGOs); scaled-up costs of immediate adaptation needs of developing country governments; and considerations of adaptation costs which are excluded from the World Bank study (as well as the above elements). These additions yield Oxfam’s estimate of adaptation costs of “at least USD 50 billion per year” for developing countries.

Some of the costs in the Oxfam assessment might be double counted. It is not clear whether community level interventions are not (at least partially) captured in ODA and GDI, which are both already accounted for separately. For example, at least one of the three examples of community level interventions that are provided in the report was financed by a bilateral donor (in other words should be covered under ODA). Second, the report extrapolates costs from a small number of point estimates to the global scale. For example, cost estimates for three local community level projects are normalised to per capita terms and then scaled up to the 2.8 billion of the world’s poor who live on less than USD 2 per day, assuming that 40% of them are in need of such interventions at any given time. Likewise, cost estimates of immediate adaptation needs in 13 NAPAs are first normalised (in terms of population, GDP, or land area) and then scaled up, first to all LDCs, and then to all developing countries. This scaling up is even more

problematic, as the underlying costs which are being scaled up have not been well substantiated in the first place (see the previous section on national estimates).

The World Bank study and approach also serves as a primary input for the costing assessment by the UNDP (2007), which sets annual investment targets required for adaptation for 2015. The calculation of adaptation costs is based on three elements: costs of “climate-proofing” development investments, costs of adapting poverty reduction strategies to climate change and increased costs of strengthening disaster responses. The cost of climate-proofing investments in developing countries until 2015 is based on an update of the World Bank study using 2007 data on ODA,¹⁷ FDI,¹⁸ and GDI.¹⁹ The proportion of climate sensitive ODA is lowered from the initial 40% used by the World Bank to 17-33%, while the climate sensitive parts of FDI and GDI remain the same as those provided by the World Bank. Likewise to the Stern Review, the UNDP assume that adaptation will cost between 5-20% of total financial flows exposed to climate risks.

Overall costs for climate-proofing investments are estimated by UNDP (2007) to range between USD 5-67 billion per year, with a mid range of USD 30 billion per year. Finally, a target of “at least USD 44 billion per year” is set for climate-proofing development investments.²⁰ The study also accounts for costs that are needed to “strengthen social protection programmes and scale up aid in other key areas” for which a target of “at least USD 40 billion per year” by 2015 is set.²¹ Finally, to strengthen the disaster response system, an increase in climate-related disaster response of USD 2 billion per year in bilateral and multilateral assistance by 2015 is assumed. Adding these cost numbers, the report suggests a lower bound ballpark estimation of adaptation costs of USD 86 billion per year. However, this figure limits the lower bound estimate of costs of “climate-proofing” development at USD 44 billion per year, instead of the actual low range estimate of USD 5 billion per year (provided in the same report). If the USD 5 billion per year figure was taken as the lower bound estimate for

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- 17. Estimated at USD 107 billion per year.
 - 18. Estimated at USD 281 billion per year.
 - 19. Estimated at USD 2 724 billion per year.
 - 20. This figure is based on the assumption that adaptation financing requirements in developing countries will represent around 0.1% of developed country GDP (the approximate level in 2005 based on World Bank methodology).
 - 21. This would amount to 0.5% GDP for low and lower-middle income countries.

“climate-proofing” development investments, then the total lower bound estimate for adaptation costs would be of USD 47 billion per year.

Adaptation costing in UNFCCC analysis of investment and financial flows (2007)

The UNFCCC analysis examines investment and financial flows for adaptation to climate change in five sectors: agriculture, forestry and fisheries; water supply; human health; coastal zones; and infrastructure. The results were examined for the year 2030, under a reference and a “mitigation” scenario, both on a global basis and for developing countries.²² The total annual costs for adaptation by the year 2030 for these five sectors are calculated to be in the range of USD 49-171 billion per year globally, of which USD 28–67 billion per year will be in non-Annex I countries (UNFCCC, 2007). Overall, this corresponds to 0.2-0.8% of global investment flows or 0.06-0.21% of projected GDP in 2030 (Smith, 2007).

The UNFCCC analysis is more in depth than the estimates reviewed in the preceding section. In particular, in most sections of this analysis there is a clearer representation of the specific adaptation activities that are being costed. The sectoral cost analyses follow different methodologies, both because of the specific nature of adaptations in particular sectors and due to the characteristics of the underlying literature that they draw upon. These analyses have been reviewed in greater detail in the section on sectoral estimates. The underlying cost analysis for certain sectors (particularly coastal zones and water resources) is more in depth and better substantiated than for other sectors.

With regard to the overall multi-sectoral estimates from the UNFCCC analysis, the costs of adapting infrastructure stand out as they have the widest range and their upper bound is an order of magnitude (or more) higher than costs in other sectors. Out of the upper bound of USD 171 billion that adaptation is estimated to cost annually on a global scale in the year 2030, USD 130 billion is attributed to infrastructure (Smith, 2007). Likewise, for developing countries, infrastructure costs contribute USD 41 billion out of the estimated upper bound of USD 67 billion in adaptation costs, again for 2030. The costs for infrastructure, however, are not derived in the study (Satterthwaite, 2007). Rather, the study relies on the

22. “Developing countries” here are defined as non-Annex I parties to the UNFCCC. The World Bank study analysis of costs of climate proofing in developing countries (reviewed earlier) was based on ODA recipients. The two categories overlap, but there are nevertheless some differences.

same percentage that adaptation is going to cost between 5-20% of the total infrastructure investment, which was assumed in the World Bank study. Other segments of the UNFCCC assessment (e.g. agriculture and water resources) are also based on assumed percentages of what adaptation might cost, which are then applied to very large numbers of baseline investments to yield dollar amounts of adaptation costs. There are also issues of both undercounting, due to the narrow scope of impacts and adaptations that have been considered, as well as potentially double-counting investments. For example, infrastructure is costed separately, and is an integral component of coastal, water sector, and agricultural adaptations as well.

Overall evaluation of global, multi-sectoral estimates

While potentially relevant for the global discussion on adaptation and its financing, existing multi-sectoral estimates face serious limitations. There has been a premature and very rapid convergence around initial estimates that are quite sensitive to the assumptions made. Two particular assumptions stand out: (i) the percentage value of assets/flows that might be exposed to climate risk; and (ii) the percentage incremental costs of “climate-proofing” such exposed assets. Very little or no analytical information is currently available on either of these parameters and, therefore, the assumptions that are made become particularly critical, given the very large magnitude of baseline investments to which these percentages are applied.

Further, in most cases the global adaptation cost estimates do not have a direct attribution to specific adaptation activities, nor are the benefits of adaptation investments articulated. There are also issues of double counting, and scaling up to global levels from a very limited (and often very local) evidence base. At the same time, many sectors and adaptations have not been included in such estimates. Existing global adaptation cost studies have also tended to stack upon the assumptions made in preceding studies, and are not really based upon independent analysis. Therefore, the “consensus” on global adaptation costs, even in order of magnitude terms, may be premature and not a useful guide to shape international decisions on adaptation financing.

This analysis, therefore, supports the more cautious view taken by the IPCC Fourth Assessment report that “comprehensive, multi-sectoral estimates of the global costs and benefits of adaptation are currently lacking” (IPCC, 2007b, Chapter 17, p. 719).

Concluding remarks

This chapter provides a critical assessment of adaptation costs and benefits in key climate sensitive sectors, as well as across sectors at the local/regional, national and global levels. There is a relatively large amount of information available about adaptation costs at the sectoral level. In particular, there is a significant body of literature on the costs and benefits of adaptation measures in coastal zones. In the agricultural sector, more work has been done on quantifying the benefits of adaptation strategies with limited information available on the costs of such measures. In terms of coverage, there is fairly comprehensive geographical coverage in the case of coastal zones and agriculture. However, for the other sectors covered in this report, the information on costs of adaptation was more limited and piecemeal. The discussion on energy has been largely limited to the United States, while only sporadic and largely local level information on adaptation costs and benefits is available for the water resources, public health, tourism and infrastructure sectors.

The studies on adaptation costs for coastal zones show that while significant investment will be needed for coastal protection, total costs of protection represent a small percentage of national GDP, frequently less than 0.1% of GDP. However, there are significant regional differences and the share of protection costs as a percentage of GDP might be significantly higher for certain small island states. In the agricultural sector, a general finding from global-level studies is that relatively modest adaptation measures can significantly offset any declines in projected yield as a result of climate change. While farm level adjustments have been found to yield significant benefits, these benefits are not translated equally to all regions. In the water sector, research seems to indicate that in regions where rainfall is expected to increase, it is waste water treatment that may become problematic and impose substantial cost in order to adapt public infrastructure. In contrast, in regions where there will be less rainfall or where water availability will decline due to glacier retreat, investments in enhanced storage, as well as increasing the efficiency of water allocation will become highly valuable. In the energy sector, the majority of studies carried out for the United States conclude that adaptation costs of increased cooling will be greater than the benefits associated with reduced heating demands. For the other sectors there are only a few isolated estimates of adaptation costs and benefits.

Aggregate, multi-sectoral studies on costs of adaptation are relatively new. National costing of adaptation can be found in the NAPAs of the Least Developed Countries. The NAPAs identified adaptation activities based on a bottom-up approach engaging a wide variety of stakeholders and are,

therefore, likely to better represent/reflect priorities on the ground. In addition, the NAPAs identified some “atypical” adaptation priorities, which are missed in more theoretical studies. However, the NAPAs focus only on priority adaptation activities and do not provide guidance as to the type of adaptation actions that will be required over the long term. The type of priority activity identified may also be influenced by the group of stakeholders present during the NAPA process, and may, therefore, not necessarily reflect all priority actions required. Furthermore, the link between the adaptation action and the extent to which the damages are offset is not specified with any detail in the NAPAs. Finally, there is a concern about whether the priority actions identified will necessarily facilitate long-term adaptation to climate change.

Global, multi-sectoral estimates of adaptation costs are very recent. They suggest that adaptation to climate change at the global level will cost several billions of dollars per year. While potentially relevant for the global discussion on adaptation and its financing, existing multi-sectoral estimates face serious limitations. There has been a premature and very rapid convergence around initial estimates that are quite sensitive to the assumptions made. In most cases the estimates do not have a direct attribution to specific adaptation activities, nor are the benefits of adaptation investments articulated. There are also issues of double counting, and scaling up to global levels from a very limited (and often very local) evidence base. At the same time, however, many sectors and adaptations have not been included in such estimates. For all these reasons “headline” global adaptation cost numbers can be seriously misleading if adequate attention is not paid to the assumptions that underlie particular empirical estimates.

The analysis of adaptation costs and benefits at the sectoral, national, and global levels also raises some more fundamental issues. Adaptation is a rather nebulous concept, whose boundaries have not yet been clearly defined. What does or does not fall within the purview of adaptation remains ambiguous and could significantly affect the calculation of costs. For example, should adaptation only consider actions that reduce climate risks or should it also consider actions that enhance a system’s capacity to respond to climate risks? If adaptation actions need to reduce risk and enhance capacity then the costs are likely to increase significantly, as a much broader set of actions will be included.

In addition, it is difficult to separate between adaptation to climatic stimuli only and adaptation to all risks. For example, farming practices, land use planning, infrastructure design might all reflect some considerations of current or anticipated climate but it might not be feasible to cost the climate component as such decisions are also simultaneously conditioned by a

whole range of other (and often more influential) factors. In the water sector, costs often reflect adaptation responses to demographic and economic changes as well as to climatic changes. Meanwhile, separating the costs of adapting to climate variability and climate change adds a further layer of complexity because few examples of adaptation are as cut and dry as building the next increment of a sea wall to protect against climate change induced sea level rise.

Most studies only consider a very narrow scope of climate change impacts. For example, studies assessing adaptation in the coastal zones tend to focus only on inundation of coastal zones and wetlands and ignore other impacts such as saltwater intrusion, increased disease risk and increased exposure to storm surge and flooding. Furthermore, many studies do not consider the whole spectrum of risks, and only focus on changes in means without consideration of extremes. For example, most studies assessing protection costs for coastal zones focus on impacts of gradual sea level rise and do not consider storm surges or extreme scenarios of sea level rise. The types of impacts considered will not only affect the costs of adaptation but also the choice of optimal adaptation strategies. The consideration of extreme events in addition to changes in means is likely to significantly increase the costs of adaptation.

At the same time adaptation cost estimates are also extremely sensitive to the choice of adaptation measures. Most of the costing studies reviewed in this report focus on hard measures, as these measures are more easily costed than soft measures. For example, coastal zones studies focus on hard protection measures, such as dykes and sea walls, and ignore potential ‘soft’ adaptation responses, such as land use planning and building codes. In the water sector, costing studies focus mainly on supply side measures, such as adapting and/or building storage reservoirs, dams and waste water treatment facilities, and less on demand side measures, such as promoting efficient water use through recycling, changing usage patterns, greater use of water markets and other financial and economic incentives. Such behavioural adaptations, in fact, might go a long way in lowering the overall cost of adaptation. They might also induce decisions and choices that internalise both current and anticipated climate risks. Policy instruments, including both market and regulatory mechanisms, have a very important role to play in this regard and are, therefore, investigated in further detail in Chapter 3.

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Chapter 3

Economic and Policy Instruments to Promote Adaptation

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Adaptation to climate change will comprise of thousands of actions by households, firms, governments, and civil society. This chapter provides some pointers as to how smart policy can turn private initiative into a force for adaptation. It focuses on three instruments: insurance, environmental markets and public private partnerships. Insurance has a long track record as a way to share weather risks. However, as climate damages grow insurance will become riskier. Public policy measures will be needed to overcome this problem, for example through publicly funded adaptation measures that bring down risks or by sharing the most extreme layer of risks with commercial insurers. Public policy should not, however, subsidise the systemic risks, as this may sustain activities that become progressively less viable under the changing climate. Environmental markets and pricing have a key role to play in the preservation of natural systems, even without climate change. They incentivise owners to preserve natural assets and consumers to use them carefully. From an adaptation point of view, environmental markets and pricing serve two main purposes. First, they reduce baseline stress, making systems more resilient. Second, they can help to monetise the adaptation services provided by ecosystems. Public Private Partnerships (PPPs), meanwhile, can help to overcome operational constraints and accelerate investment in infrastructure, which will likely be the most expensive part of adaptation and, therefore, put considerable strain on the administrative and financial capacity of governments. PPPs may also play a role in research and development and the search for better adaptation technologies.

Introduction

Adaptation will comprise of thousands of actions by households, firms, governments, and civil society. Sustainable adaptation will require these actors to internalise current and anticipated climate risks in their various decisions, while being mindful of the associated uncertainties. Despite a long record of dealing with climate variability there is considerable evidence that many societies and sectors remain poorly adapted, even to current climate (IPCC, 2007, Chapter 17). Further, while there are now some examples of adaptation to long term climate change, progress in this direction has been more at the level of planning than actual implementation in both developing and developed countries.

There are clearly several bottlenecks here. A key issue is the cost of adaptation and access to adequate financial resources to meet this cost. Consequently, much of the policy debate has focused on the cost of adaptation, ways to raise public adaptation funding, and allocation of adaptation costs. What has received much less attention, however, are policy and institutional bottlenecks, in particular the role of market and regulatory mechanisms in facilitating adaptation. This is quite critical, given that a majority of actions are undertaken by private actors and also because the scope of the adaptation challenge will far exceed the public budgets available to address it.

While some adaptations will provide public benefits, such as protection of coastal areas from sea level rise, many others will offer private benefits that accrue to individuals or firms, or to a consortium of such actors (Lecocq and Shalizi, 2007). Self-interest should be a sufficient incentive for such individuals or groups to undertake adaptive measures that reduce their vulnerability. Like the activities of markets, these actions do not have to be directed centrally by a public authority. In fact, this would be counter-productive and probably impossible. However, as in the case of markets, governments are called upon to provide an enabling environment that allows private agents to make timely, well-informed and efficient adaptation decisions. Where private actions fail because of external effects or other failures, governments may also have to provide adaptation as a public good. Conversely, the scale and/or efficiency of many adaptations typically undertaken by governments could be enhanced through engagement with the private sector. Again, mechanisms might need to be in place to catalyse such engagement and to ensure that it leads to the desired outcomes.

The purpose of this chapter is to move the discussion beyond cost estimation to policy instruments for promoting adaptation. The term “policy instrument” is used broadly to include mechanisms used to achieve a desired

effect through economic or legal means. Like other areas of environmental policy, these policy instruments can be directed at using markets, creating markets, regulation and legal arrangements, and engaging the public. The only qualification is that in the context of adaptation the desired effect is the reduction of adverse impacts (or enhancement of beneficial effects) due to climate change.

The rest of this chapter is organised as follows. The next section establishes the framework for examining the role of policy instruments within the context of adaptation. The nature of adaptation activities is discussed, followed by an analysis of typical climate change impacts and adaptation strategies in key climate sensitive sectors. This helps in the identification of key policy instruments which could be used to facilitate adaptation. Next, three instruments are identified that could play a key role in adaptation: insurance, price signals and environmental markets, and Public Private Partnerships (PPPs). Insurance is a recurring instrument within the context of adaptive responses in a number of sectors, particularly agriculture. Price signals and environmental markets, meanwhile, might be critical to adaptation in many climate sensitive natural resources including water and ecosystems. PPPs could potentially play a very critical role in financing and enhancing the climate resilience of infrastructure, where the costs of adaptation are disproportionately high, but also in the research and development (R&D) of new adaptation technologies. These three instruments are discussed sequentially in the following three sections. Each of these sections examines the nature and current use of the instruments, their strengths and limitations, and relevance for adaptation. The final section offers some concluding remarks.

Scope of adaptation policy instruments

The process of adapting to climate and climate change is complex and multifaceted. It covers all aspects of society and consists of a multitude of behavioural, structural and technological adjustments. As such it is difficult to do adaptation analytical justice, and a number of typologies have consequently been developed to classify adaptation activities. For example, adaptation measures have been classified according to: timing (anticipatory vs. reactive); scope (short-term vs. long-term, localised vs. regional); purposefulness (spontaneous vs. planned, passive vs. active adaptation); and adapting agent (private vs. public adaptation, societies vs. natural systems).

For the purpose of examining policy instruments, it is suitable to employ the following classification of generic adaptation options introduced in the IPCC Third Assessment Report (IPCC, 2001, Chapter 18, after Burton, 1996):

- **Bear losses.** Bearing loss occurs when those affected have no capacity to respond in any other ways (for example, in extremely poor communities) or where the costs of adaptation measures are considered to be high in relation to the risk or the expected damages.
- **Share losses.** This involves spreading the losses among a wider community. Such actions take place both in traditional and modern societies. In traditional societies, losses are typically shared among extended families and village-level or similar communities. Complex modern societies share losses through insurance, public relief, rehabilitation, and reconstruction paid for from public funds.
- **Modify the threat.** For some risks, it is possible to exercise a degree of control over the environmental threat itself, for example via flood control.
- **Prevent effects.** A frequently used set of adaptation measures involves steps to prevent the effects of climate change. These measures can in turn be grouped into: (i) structural/technological measures; (ii) legislative/regulatory instruments; (iii) institutional / administrative measures; (iv) market-based instruments; and (v) on-site operations.
- **Change use.** Where the threat of climate change makes the continuation of an economic activity impossible or extremely risky, consideration can be given to changing the use. For example, farm land may be converted back into wetlands to protect coastal zones.
- **Change location.** Another response is to change the location of economic activities. There is considerable speculation, for example, about relocating major crops and farming regions away from areas of increased aridity and heat to areas that are currently cooler and which may become more attractive for some crops in the future.
- **Research.** The process of adaptation can be advanced by research into new technologies and new methods of adaptation, for example in agriculture (new cultivars) and health (new treatments for climate change-related diseases).
- **Encourage behavioural change through education, information and regulation.** Another type of adaptation is the dissemination of knowledge through education and public information campaigns, leading to behavioural change.

Identifying specific policy instruments that facilitate these generic adaptation strategies requires additional detail on the specifics of the impacts

faced by particular sectors as well as the potential adaptation strategies. Starting with the main impacts of climate change across key sectors, Table 3.1 lists some of the main adaptation measures that fall under the above-mentioned generic categories. The last column of this table then identifies specific policy instruments that can be used to facilitate these adaptations.

Table 3.1 shows that in principle there might be a range of policy instruments that can facilitate adaptation in the various sectors. The table of course is intended to be illustrative and not comprehensive. Nevertheless, it does have a number of recurrent policy instruments that are relevant to adaptation in many sectors, including:

- **insurance schemes** (majority of sectors),
- **price signals/markets** (*e.g.* water and ecosystems),
- **PPPs** (*e.g.* flood defence, coastal protection and water),
- **microfinance schemes** (*e.g.* agriculture, weather extremes),
- **regulatory incentives** (*e.g.* building standards and zone planning),
- **R&D incentives** (*e.g.* agriculture and health).

The following sections examine the first three of these instruments, *i.e.* insurance schemes, price signals and environmental markets, and PPPs in further detail. Specifically, the focus is on the description and current application of each of these instruments, their strengths and limitations, and whether and how they can be applied to address the specific challenges posed by climate change.

Risk sharing and insurance

Insurance – risk sharing – has been used to deal with climate variability and weather risks for centuries. Risk sharing owes its popularity to notions of economic efficiency, risk aversion, and a sense of solidarity at times of hardship. It is also good business. The insurance sector is a vital part of modern financial markets. It is also a sector that has already been forced to evolve in order to cope with new varieties of environmental risk. As climate changes and historical weather records become less useful, the insurance sector will have to develop new ways of spreading risk away from those affected, while encouraging those at risk to adapt to the new environment.

Table 3.1. Climate impacts, adaptation options and policy instruments

Sector	Main impacts	Adaptation options	Potential policy instruments
Agriculture	Reduction in global yields of crops like rice, wheat, maize and soybean, with particularly high losses in tropical areas close to temperature thresholds and arid, semi-arid areas. Direct and indirect (through quality and quantity of food, water) impact on farm animals (health, growth, milk and wool production, fertility). Increased prevalence of pests, weeds and disease. There are also positive impacts, including increased productivity in some crops due to CO ₂ fertilisation; longer growing seasons in high latitudes.	• Share the loss: crop insurance • Prevent the loss (structural, technological): investment in new capital • Prevent the loss (market-based): removal of market distortions (e.g. water pricing) • Prevent the loss (market-based): liberalisation of agricultural trade to buffer regionalised losses • Change use: change of crops, planting dates, farming practices • Research: development of heat and drought resistant crops	• Price signals/markets • Insurance instruments • Microfinance (e.g. to finance capital investment) • R&D incentives
Coastal zones	Inundation, flood and storm damage through sea surges and backwater effects; wetland loss; erosion; saltwater intrusion in surface and ground waters; rising water tables and impeded drainage.	• Prevent the loss (structural, technological): coastal defences/sea walls; surge barriers; upgrade of drainage systems, saltwater intrusion barriers • Prevent the loss (on-site operations): sediment management; beach nourishment; habitat protection (e.g. wetlands, mangroves) • Prevent the loss (institutional, administrative): land use planning • Change location: relocation; set back areas	• Regulatory incentives (zone planning) • Price signals/markets (e.g. differentiated insurance premiums; valuation of ecosystems) • Financing schemes (PPPs or private finance for coastal defence schemes)

Table 3.1. Climate impacts, adaptation options and policy instruments (cont.)

Sector	Main impacts	Adaptation options	Potential policy instruments
Health	Higher incidence of heat stress and heat-related mortality; particularly in cities and during heat waves; fewer winter deaths; change in the prevalence of vector borne diseases, such as malaria and dengue fever. There will also be health effects from extreme weather events (see below).	- Prevent the loss (structural, technological): air conditioning, building standards - Prevent the loss (institutional, administrative): improvements in public health; vector control programmes; disease eradication programmes - Research: R&D on vector control, vaccines, disease eradication - Education/behavioural: behavioural change (work breaks, maintain hydration)	- R&D incentives - Regulatory incentives (e.g. building codes) - Insurance
Water resources	Change in the volume, timing and quality of water flows; increased rainfall variability; change in peak streamflow from spring to winter; more frequent and severe water shortages; flooding after severe water discharges; decrease in water quality through salination, higher temperature, lower flow in some areas (higher flows in others).	- Prevent the loss (structural, technological): loss reduction (leakage control; conservation plumbing); capacity increase (new reservoirs, desalination facilities) - Prevent the loss (institutional/administrative): water allocation (e.g. municipal vs. agricultural use); risk management to deal with rainfall variability - Prevent the loss (market-based): water permits, water pricing - Education/behavioural: rational water use, rainwater collection	- Price signals/markets (water pricing, trade in water permits) - Regulatory incentives (hosepipe bans, etc.) - Financing schemes (adjustments to terms of water PPPs)

Table 3.1. Climate impacts, adaptation options and policy instruments (cont.)

Sector	Main impacts	Adaptation options	Potential policy instruments
Ecosystems	Change in the extent, distribution and health of species; migration (e.g. fish stock, birds); change in behaviour (e.g. earlier nesting); loss of species unable to move or too slow to adapt.	• Bear the loss: increase ecosystem resilience (e.g. reduce baseline stress) • Prevent the loss (legislative, regulatory): habitat protection (i.e. reduce baseline stress) • Prevent the loss (institutional, administrative): change in natural resource management (e.g. sustainable fishery, forestry); environmental policy • Prevent the loss (market-based): eco-tourism, market for ecological services • Change location: facilitate species migration (e.g. migration corridors) • Research: breeding and genetic modification for managed systems	• Price signals/markets (e.g. ecosystem markets) • Regulatory incentives (e.g. zone planning, environmental standards) • Microfinance schemes (e.g. ecotourism) • R&D incentives
Settlements and economic activity	Malfunctioning infrastructure; redirection of tourist flows (summer heat, lack of snow, sea level rise); migration/change in population dynamics; increase in energy demand from space cooling, but reduction in winter heating demand.	• Share the loss: insurance, weather derivatives • Prevent the loss (structural, technological): climate-proofing of housing stock and infrastructure • Change location: zone planning, location decisions	• Regulatory incentives (building standards) • Price signals/markets (e.g. adaptation-dependent insurance premiums) • Insurance schemes • Financing schemes (adjustments to infrastructure PPPs)

Table 3.1. Climate impacts, adaptation options and policy instruments (cont.)

Sector	Main impacts	Adaptation options	Potential policy instruments
Extreme weather events	Higher frequency and severity of extreme weather events, such as hurricanes, floods and storms. Damage to infrastructure, housing stock; interruption of economic activity; direct health effects through death and injuries, indirect health effects from water contamination and bad sanitary conditions.	- Share the loss: insurance; spreading of risks beyond the insurance industry (e.g. through cat bonds) - Prevent the loss (structural, technological): flood barriers; storm/flood-proof infrastructure, housing stock - Prevent the loss (institutional, administrative): early warning systems; enhanced disaster management - Change location: zone planning, location decisions	- Insurance schemes - Price signals/markets (e.g. adaptation-dependent insurance premiums) - Regulatory incentives (building codes, zone planning) - Financing schemes (private finance or PPPs for defence structures)

From a public policy point of view, the question will be whether these adjustments result in a sufficient level of insurance cover and a fair allocation of risk. This section reviews the adaptation challenges in the insurance sector.

Scope of current products

Traditional indemnity-based insurance covers the policy holder against the loss of an asset (such as a crop or a home) and has long been used to also address weather related risks. A core weakness of these products is the moral hazard created by the indemnity based products. Although this method should result in the payout being close to the actual loss incurred, there is a perverse incentive for the insured party not to undertake risk reduction if they know that the damage will be covered by a claim based policy. In such cases insurance may actually impede adaptation or even promote maladaptation. Furthermore, traditional insurance involves asymmetric information. This occurs when one party has more or better information than the other creating an imbalance in power in transactions, which can lead to an under- or over-estimation of risk. Finally, the settling of claims is time consuming and costly.

A potential solution to some of these problems has been the creation of different trigger options that may be more suitable for dealing with climate change related risk. In particular, as a large number of weather conditions can be quantified, for example rainfall, temperature and wind speed, insurance products can be triggered by a predetermined quantified weather scenario. Beyond these “parametric” triggers, index-linked options have also been developed that calculate the payout according to “industry loss” and “modelled loss” triggers.

Index-based insurance reduces moral hazard since payment and actual damage are not directly linked. As the insured party receives a payout irrespective of the losses experienced, the incentive to prevent and mitigate risk is preserved. There is no need for an assessment or verification of actual damage so the transaction costs are lowered and the speed of payout is improved. These benefits are particularly relevant when designing schemes to insure parties in developing countries who are at risk from catastrophic weather conditions.

In addition, index-based insurance can facilitate the transfer of risk to capital markets by standardising contracts. By basing contracts on publicly available information, the asymmetries associated with traditional insurance are reduced, encouraging greater participation. Finally, index insurance will incentivise greater measurement of weather patterns and the development of more sophisticated models. Table 3.2 summarises close to 30 index insurance schemes that have been put in place in developing countries in recent years.

Table 3.2. Summary of index-based risk transfer products in lower income countries

Country	Risk event	Contract structure	Index measure	Target user	Status	Source
Bangladesh	Drought	Index insurance linked to lending	Rainfall	Smallholder rice farmers	In development. Pilot launch planned for 2008.	Barnett and Mahul, 2007
Caribbean Catastrophe Risk Insurance Facility	Hurricanes and earthquakes	Index insurance contracts with risk pooling	Indexed data from NOAA and USGS	Caribbean country governments	Implemented in 2007	Barnett and Mahul, 2007; Isom, 2007
China	Low, intermittent rainfall	Index insurance	Rainfall and storm day count	Smallholder watermelon farmers	Implemented in Shanghai only in June 2007. Includes a 40% premium subsidy.	Barnett and Mahul, 2007
Ethiopia	Drought	Index insurance	Rainfall	WFP operations in Ethiopia	USD 7 million insured for 2006. Policy not renewed for 2007 due to lack of donor support.	Skees <i>et al.</i> , 2006; Syroka and Wilcox, 2006
	Drought	Index Insurance	Rainfall	Smallholder farmers	2006 pilot, currently closed due to limited sales.	Barnett, Barret and Skees, 2008
	Drought	Weather derivative	Satellite and weather data	NGO	Implemented 2007	Swiss Re, 2007
	Drought		Rainfall		In development	Syroka, 2007
India	Drought and flood	Index insurance linked to lending and offered directly to farmers	Rainfall	Smallholder farmers	Began with pilot in 2003. Now index insurance products are being offered by the private sector and the government.	Manuamom, 2007; Ibarra and Syroka, 2006
Kazakhstan	Drought	Index insurance linked to MPCJ programme	Rainfall	Medium and large farms	In development	Barnett and Mahul, 2007
Kenya	Drought	Weather derivative	Satellite and weather data	NGO	Implemented 2007	O'Hearne, 2007
Mali	Drought	Weather derivative	Satellite and weather data	NGO	Implemented 2007	Swiss Re, 2007

Table 3.2. Summary of index-based risk transfer products in lower income countries (cont.)

Country	Risk event	Contract structure	Index measure	Target user	Status	Source
Malawi	Drought	Index insurance linked to lending	Rainfall	Groundnut farmers who are members of NASFAM	Pilot began in 2005. 2 500 policies sold in 2006 pilot season. USD 7 000 in premium volume.	Aldeman and Haque, 2007; Lefley and Mapfumo, 2006
Mexico	Natural disasters impacting smallholder farmers, primarily drought	Index insurance	Rainfall, wind speed and temperature	State governments for disaster relief. Supports the FONDEN programme.	Pilot began in 2002. Available in 26 of 32 states. Currently 28% (2.3 million ha) of dry land cropland is covered.	Agroasemex, 2006a; Skees <i>et al.</i> , 2006
	Major earthquakes	Index-linked CAT bond and index insurance contracts	Richter scale readings	Mexican government to support FONDEN	Introduced in 2006. CAT bond provides up to USD 160 million. Index insurance coverage up to USD 290 million.	Wenner, 2007; Cardenas, 2006
	Drought affecting livestock	Index insurance	Normalised difference vegetation index	Livestock breeders	Launched in 2007. Sum insured USD 22.5 million across 7 states. Insured 913 000 cattle.	Agroasemex, 2006b
	Insufficient irrigation supply	Index insurance	Reservoir levels	Water users groups in the Rio Mayo area	Proposed	Skees and Leiva, 2005
	Large livestock losses due to severe weather	Index insurance with direct sales to herders	Area livestock mortality rate	Nomadic herders	Second pilot sales season of pilot completed in 2007; 14% participation.	Mahul and Skees, 2005; Skees and Enkh-Angalan, 2002
Morocco	Drought	Index insurance	Rainfall	Smallholder farmers	No interest from market due to declining trend in rainfall	Barnett and Mahul, 2007; Skees <i>et al.</i> , 2001; Stoppa and Hess, 2003

Table 3.2. Summary of index-based risk transfer products in lower income countries (cont.)

Country	Risk event	Contract structure	Index measure	Target user	Status	Source
Nicaragua	Drought and excess rain during	Index insurance	Rainfall	Groundnut farmers	Launched in 2006	Barnett and Mahul, 2007; Syroka, 2007
Peru	Flooding, torrential rainfall from El Niño	Index insurance	ENSO anomalies in Pacific Ocean	Rural financial institutions	Proposed	USAID, 2006; Skees, Hartell and Murphy, 2007
	Drought	Index insurance linked to lending	Area-yield production index	Cotton farmers	Proposed	Carter, Boucher and Trivelli, 2007
Senegal	Drought	Index insurance linked to area-yield insurance	Rainfall and crop yield	Smallholder farmers	Proposed	Barnett and Mahul, 2007; Swiss Re, 2007
Tanzania	Drought	Index insurance linked to lending	Rainfall	Smallholder maize farmers	Pilot implementation in 2007	Barnett and Mahul, 2007; Swiss Re, 2007
Thailand	Drought	Index insurance linked to lending	Rainfall	Smallholder farmers	Pilot implementation in 2007	Barnett and Mahul, 2007; Manuamorn, 2006
Ukraine	Drought	Index Insurance	Rainfall	Smallholders	Implemented in 2005; currently closed due to limited sales.	Barnett and Mahul, 2007; Skees, Hess and Ibarra, 2002
Vietnam	Flooding during rice harvest	Index insurance linked to lending	River level	The state agricultural bank and, ultimately, smallholder rice farmers	In development, a draft business interruption insurance contract is being considered by the state agricultural bank.	Skees, Hartell and Murphy, 2007

The inherent disadvantage of index insurance is the lack of relation between the predetermined payout and actual damage. This “basis risk” results in a potential lack of correlation between premium and payout that is difficult to correct due to the increasing unpredictability of the climate. Also, “parametric” index-based triggers only cover one potential cause of damages, for example low rainfall leading to drought, leaving the sponsor unprotected against other causes of failure, for example, poor seed. So while the market for index insurance is still immature, further developments are required in order to encourage more extensive participation from the private sector. One such advancement is the creation of hybrid triggers that use more than one trigger type in a single transaction or tranche. These can be used on multi-peril transactions using a different kind of index trigger for each. Alternatively, hybrid triggers can involve the application of different trigger types in a sequential fashion in order to determine the loss from a covered event.

Weather derivatives are financial instruments that can be used as part of a risk management strategy to reduce the risk associated with adverse or unexpected weather conditions. This market instrument covers low cost, high probability events and the most common contracts are based on temperature indexes. It also covers contracts on rainfall, snowfall and storm risks. These instruments were the first form of index insurance, where payouts are linked to the occurrence of a certain weather event. In 2002, it was estimated that USD 1 trillion of the US economy was weather-sensitive, implying an enormous potential market for these new hedging instruments.

Weather derivatives are now entering their second decade of existence. Despite a decline in contracts between 2006-07, the trading volumes and values are still above pre-2006 levels and with climate change awareness growing, financial markets are likely to continue to base products on the increasingly variable weather patterns. In particular, energy utilities use these derivatives to hedge against the consequences of temperatures deviating from the seasonal average. Weather derivatives also have potential for other sectors whose profits are affected by the weather, including agriculture, retail sales, the leisure sector and the construction industry. In order to present marketable products to these new customers, the market has diverged from temperature-indexed contracts to derivatives of precipitation, both rain and snow and wind. One likely development given the general market conditions is a move towards more cross-market trading and correlation strategies with other markets. In particular, there is great potential demand from companies seeking to hedge their greenhouse gas emissions risks. The strong link between weather, levels of energy generation and therefore emissions will encourage power generators to structure trades that combine carbon and weather derivatives.

Catastrophe bonds. As the relationship between payouts and premiums has become increasingly distorted, insurers have come to realise that they lack the resources to deal with large-scale losses on their own. In order to enable them to continue offering protection against extreme events, one option has been to attract extra funding from the capital markets by securitising some of the risk in bonds, which could be sold to high-yield investors. Catastrophe (cat) bonds are such securities that transfer risk from sponsors to investors. The coupons are normally a reference rate plus an appropriate risk premium. However, if the bond is triggered (through a pre-defined loss or index-based level), the investor will forfeit a preset amount of the capital invested and the insured party receives a payout relevant to the degree of loss or scale of index. Although the “cat” bonds have primarily been used in developed countries, their viability is currently being examined by the World Bank for developing country contexts.

Other instruments. Two instruments that are currently being explored to address climate-related risks are Pooling Cash Reserves and Debt Indemnification. **Pooling Cash Reserves** are being tested as a form of collective self-insurance by the Eastern Caribbean Central Bank which is accumulating mandatory contributions from member governments. These reserves could be used to draw loans in case of natural disasters. **Debt Indemnification** is being used under the Commonwealth and Smaller States Disaster Management scheme. It provides insurance to risk-prone governments so that they can continue to service their debt following natural disasters based on a flat rate premium of 1% of the value insured (Burton *et al.*, 2006).

Implications for adaptation

The immediate effect of climate change will be to raise the demand for insurance products. Increased weather variability will make risk reduction a more attractive proposition. However, climate change will also increase the cost of insurance and this may curb some or all of the extra demand. Higher weather variability and more extreme events will mean higher expected losses and higher payouts. Insurance companies will pass on that extra cost to clients wherever possible. Moreover, uncertainty about climate change will make insurance more risky, at least in the short term, as historic statistics and loss probabilities can no longer be relied upon. Insurance providers will want to be compensated for that extra risk.

The challenge for the insurance industry, as it seeks to reduce climate change risks and turn climate change into a business opportunity, will be two-fold. First, there will be a need for extra capital and ways to spread risks beyond the relatively small insurance sector. This is necessary to absorb

higher average payouts and to deal with more frequent and higher spikes in payouts following an extreme event. Catastrophe bonds have, in the past, been used to spread insurance risk in the financial sector more broadly. In fact they have been specifically designed for that purpose, and as such they may gain more prominence as the climate changes. Other companies may choose mergers or “rights issues”¹ to increase their financial depth.

The second challenge for the insurance sector is to improve the accuracy and resolution of hazard data and the likely impacts of climate change. Although insurance companies are beginning to use simulation models to estimate likely loss profiles, the pricing of premiums is still based on historical records, which are no longer a reliable guide for future weather-related losses. However, developing an analytical understanding of future climate change risks is extremely difficult. An accurate risk assessment requires detailed knowledge not only of the physical impacts of climate change at the regional level (precipitation, temperature, wind speeds, frequency and severity of extreme events) but also of socio-economic developments and adaptation measures that affect insurance density and future vulnerability. Insurance companies will look to public bodies – universities, meteorological offices and research laboratories – for relevant climate information and vulnerability data. Some of the necessary research may be sponsored by the insurance companies or carried out jointly with their in-house research teams. For example, in the European Alps where climate change has implications for a number of natural hazards, insurance companies are beginning to examine these implications on their pricing and, in one case, are also funding the development of climate change scenarios (Jetté-Nantel and Agrawala, 2007). However, despite any improvements in climate forecasting capabilities, a fundamental challenge in anticipating future climate risks is that many of the climatic changes are not monotonic, which makes identification of trends very difficult. The challenge this poses for pricing insurance schemes is illustrated through the case of rainfall in the Sahel in Box 3.1.

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1. Means of raising equity whereby a company offers its current shareholders the right to purchase a specified number of additional shares at a specified (attractive) price within a specified time.

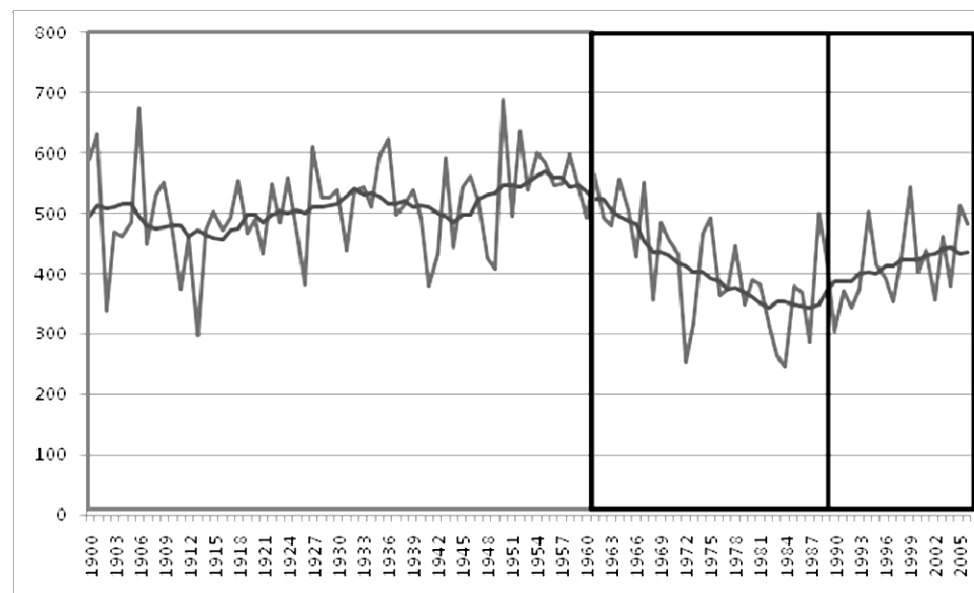
Box 3.1. Rainfall variability and the challenge of pricing insurance

As index insurance is being increasingly pursued as a tool to address the risks of climate change in developing countries, caution is needed to understand whether or not it might, in fact, be an appropriate strategy. In theory, the process of pricing weather index insurance provides an indication of risk exposure: the higher the exposure, the higher the insurance premium. Relaying this information to the potential insured gives clear signals regarding the costs of the risks and, may provide the necessary incentives for the required adaptations.

Pricing weather risk in the future, however, is extremely difficult. Consequently, premiums are often set based on historical data of the index (such as rainfall). The problem, however, is that past trends might not accurately reflect future outcomes. This is further complicated if the historical record shows different trends over different periods of time, which is not entirely uncommon for rainfall. In this case, depending on the time reference used, the insurance premiums could be very different and may send very different signals in terms of adaptive responses.

This is illustrated by using the example of rainfall in the Sahel, where rainfall was centred around an average of 500 mm between 1900 and the early 1960s, followed by a steady decline until the mid-1980s, and an upswing since then (see figure below).

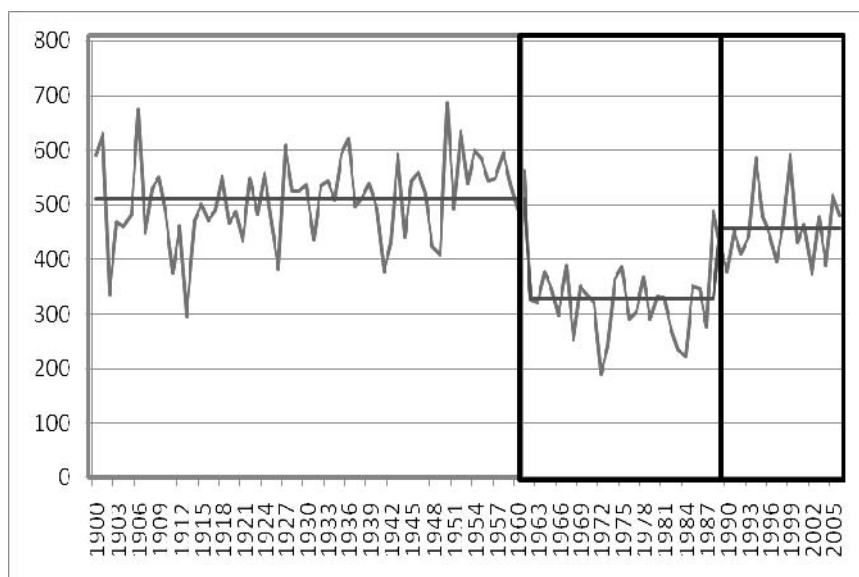
Sahelian rainfall from 1900 to 2006



Imagine the hypothetical case of providing insurance for the dominant crop in the region which requires 400 mm annual rainfall to sustain. If a farmer needs a contract that pays when rainfall is less than 400 mm, one can consider how an insurance provider might begin pricing such a contract with the vantage point of having data from different periods in time (1900-61, 1962-89, and 1990-2006), as shown in the figure above. For 1962, the historical record (1900-61) would reflect a slight upswing, centred around 500 mm of rainfall. For 1990, meanwhile, having only data from 1962 to 1989 would result in a very different conclusion about the future average rainfall as the forecast from this series of data is around 310 mm. While for 2007, the recent historical record (1990-2006) would reflect a slight upward trend again.

An insurer having the vantage point of using only data represented in each of the panels in the figure above, would adjust the data by accounting for the trend. The second figure, below, illustrates the type of adjustments that would be done to “remove the trend” and re-centre the variance in the data around the forecasted trend data at the end of each of the three time periods. Writing a rainfall insurance for rainfall below 400 mm would be feasible at the end of the data in the first time period, and likely at the end of the data in the last time period. It would clearly not be feasible at the end of the data that appear in the middle time period. In this case, the forecast of the central tendency for 1990 is 310 mm. Based on the information from the middle time period, a policy that pays for rainfall below 400 mm would be expected to pay in every year, which is clearly not viable.

Weather data adjusted for trends given the vantage point of 1962, 1990 and 2007



Important lessons

The Sahel case, while somewhat unique, has two important pointers for pricing insurance under climate change. First, it highlights the limitations of using retrospective information as a guide to pricing premiums when the parameter that is being indexed is exhibiting considerable variability. Second, the experience from the middle period that is examined (1962-89) shows that insurance may not be a viable option if there is a monotonic trend in the central tendency. In this case insurance was clearly not suitable for the point of reference for 1990. During the 1970s and 1980s, the region was experiencing a strong desiccation trend, which would have led to very high insurance premiums. In this situation, subsidising insurance premiums to improve household access to insurance is more likely to hinder needed household adaptations to the new climatic conditions, increasing household risk in the long term. Thus, if there are distinct trends in weather data that change the central tendency, insurance is less likely to be a viable solution. Attempting to subsidise the cost of insurance when the central tendency is changing will be more costly and more clearly recognised as a subsidy by farmers, and consequently, more likely to delay adaptation.

Note: Figures created by GlobalAgRisk, Inc. (2008) from data provided by International Research Institute for Climate and Society, Columbia University.

From a public policy point of view, the main issue is whether the adaptation action taken by the insurance industry results in the “right outcome” in terms of the availability and level of cover and the distribution of risks. In an ideal scenario, competitively priced insurance products would send an accurate signal to the market about the economic cost of climate risks. Firms and households would respond to the price signal by climate-proofing their businesses and homes (to reduce premiums) or, if the premium is considered too high, by relocating to a less risky area. The result would be an efficient level of insurance cover and residual adaptation.

In reality this is unlikely to be the case. Several factors drive a wedge between the theoretical and actual outcome. First, as long as climate impacts are uncertain, insurance companies, which are risk-averse themselves, will overcharge for climate risk or refuse coverage of risks that might otherwise be insurable. Second, budget constraints, inertia and cultural factors will prevent people from adapting fully in the short term, especially if the optimal response is relocation. Third, insurance cover is by no means universal. Among poor households and in poor countries in particular it can be patchy.

Public policy measures may be needed to overcome these market imperfections. For example, they may take the form of publicly funded adaptation measures to bring risks (and hence premiums) down to an acceptable (and hence insurable) level. Public policy can also facilitate the

sharing of climate risks between the insurance sector and the state. Risk sharing would probably take place under a structure where regular risks are underwritten by the private sector, but exceptional damages, or damages above a certain level could be assumed by the state. Such a risk layering approach could be viable if climate change results in increased variability but without any significant changes in the central tendency (Skees *et al.*, 2008; Mahul and Skees, 2007). In this case the government could subsidise the most extreme layer of risk without creating perverse incentives and impeding adaptation decisions that might be needed to respond to more systemic climate risks. Broader use of premium subsidies, however, may reduce incentives to move away from activities that become progressively less viable under the changing climate.

Price signals and environmental markets

Natural resources, such as water, forests and ecosystems are already under considerable pressure from human activity. Climate change will add to that pressure, and it is the combined effect of global warming and these “baseline” stress factors that matters when considering the impact of climate change on natural systems.

Baseline stress from pollution, overexploitation and mismanagement has many causes, but at the root of it, from an economic point of view, is the fact that property rights over natural resources are ill defined and their services are not valued properly in the market. Water resources are overused because water is too cheap and fish stocks are overexploited because they are a common property. Economic theory has a ready-made solution to overcome these market failures. The external benefits of natural resources have to be given a market value, either by factoring them into the price (say, through environmental charges) or by creating environmental markets.

Internalising the external benefits of natural resources in this way contributes to sound adaptation for two main reasons. First, it reduces the baseline stress on ecosystems. This is a measure that makes sense even without climate change. It is also good adaptation because it makes ecosystems more resilient to cope with climate change. Second, environmental markets and pricing will facilitate adaptation by providing stronger signals about the increased scarcity of some resources (such as water) and the higher economic benefits of others. For instance, the adaptation benefits of forests (in terms of soil quality and watershed protection) and wetlands (in terms of coastal protection) are not yet reflected in the market value of these resources.

There is vigorous discussion about the extent to which economic mechanisms are actually effective in practice. There are questions about the social outcomes of trading schemes. In the case of water, one key concern would be the need to ensure that everybody has affordable access to a minimum amount of water for personal use. In some cases there are practical issues about the equity of access to markets and the potential market dominance of important players.

However, these issues can be addressed and there are many cases where natural resources can be treated as a commodity in economic terms. This section draws on such cases to illustrate the opportunities and risks of using pricing and environmental markets to encourage and promote adaptation behaviour. The focus is on water pricing, water markets and payment for ecosystem or environmental services (PES).

Water pricing

Water supply is usually addressed as three (interrelated) sub-sectors of use: domestic/municipal; industrial; and agricultural/irrigation. In many countries, even developed ones, irrigation is the biggest user in absolute terms. Whatever the use, water is very often under-valued and under-priced, especially in developing countries. This is a regulatory and policy issue. Since water supply is a natural monopoly (due to network externalities) prices are generally established by regulatory process rather than by pure supply and demand forces. The water policies of most development institutions stress the importance of efficient pricing mechanisms to promote optimal water use and encourage conservation (see for instance ADB, 2001). However, pricing reform is often difficult institutionally, politically and socially, even before climate change increases water scarcity and the competition for water resources.

In the agricultural sector, the price of water tends to be furthest away from long-run marginal costs. Moreover, water allocation is often tilted in favour of agricultural use, even though municipal use is generally of much higher value (see Briscoe, 1996). Irrigation water pricing is slowly moving towards more realistic levels, but there remains wide variation, particularly in developing countries. The pricing of irrigation water and the best way to achieve pricing efficiency remains a highly complex issue.

In the urban sector, water pricing is typically more advanced. Nevertheless, there remain difficulties and challenges. In particular there is a need to identify tariff structures that address the trade-offs between financial sustainability, efficiency of allocation, and social impacts, which include affordability (see Fankhauser and Tepic, 2007).

In the industrial sector, prices are typically closest to real cost levels (since it is politically easier to increase industrial charges than domestic ones). As might be expected, industry does respond to water prices, although in many cases the changes take time, if capital investment is required to achieve improved water efficiency.

A significant issue in responses to increased prices in all sectors is that users respond (in an economically rational way) by switching to groundwater, which is often outside the control of the local water agencies. Because groundwater is very often an under-priced or effectively free resource, users will switch once water supply costs rise above the costs of groundwater abstraction (which are generally low). This effect has been seen in urban areas with major industrial users and in rural areas with large scale irrigation users. It is a consequence of lack of control over access to a common resource, with predictable consequences of overuse, wastage and serious resource depletion. Establishing control over groundwater resources is therefore one of the major institutional challenges for water resource managers in countries across the world. It is a particular concern in the context of increasing water scarcity and variability since groundwater normally responds slowly to changes in surface water conditions and so has traditionally been a “backup” in many areas.

Water markets

There are some good examples of water markets, particularly – but not exclusively – in OECD member countries. As part of the effort to support adaptation to climate change, the challenge for policy makers is to understand the conditions in which some markets flourish and are effective and to promote the institutional changes that will encourage further open markets.

Water markets are not new: farmers and other users have always traded at the margin but structured formal markets are of more recent origin. The basic requirements for formal trading are clearly defined, exclusive and transferable rights to a defined quantum of water. This can introduce issues related to measurement of water (in time and in location) but markets generally require less information than systems that use allocation to try to achieve efficiency.

In most countries where water is scarce, systems of rights to water have emerged either informally through customs or conventions or formally through laws and regulations. Formalisation of these rights is the critical step to encouraging expanded markets. For a number of reasons, not least a culture of free market approaches, formal water markets have emerged in three main areas: the western United States; Chile; and Australia. The

country which has addressed water scarcity and the use of markets most directly and in the most integrated fashion is Australia, where adaptation to climate change is critical to the country's economic future (see Box 3.2).

In developing countries, formalisation of large scale water markets has not yet occurred, although there are many small scale activities. In India, where there are a great number of irrigation systems, there have been various examples of informal markets (see Box 3.3).

Price mechanisms to encourage efficiency and cost recovery are also used in the Mediterranean Basin, although true water trading is not yet established. Most climate models predict reduced precipitation levels for this region, adding to an already considerable baseline stress. In Tunisia, water management responsibilities and costs have shifted to Water User Associations (WUAs). A special feature of the Tunisian approach is the creation of associations of underground-water users that will improve management of the water requirements of all irrigators using a shallow aquifer. Experience will show whether such WUAs can manage aquifers in a sustainable manner. The outputs of this measure have been water savings of 25% and an increase of 33% in water-use efficiency (IPTRID, 2001). In Egypt and Turkey, WUAs have also been key to increased efficiency, while in Jordan and Morocco the public sector had a greater role in promoting water efficiency (Vidal *et al.*, 2001).

Payments for ecosystem services

In the past decade, there has been increasing development of the use of payments for environmental or ecosystem services (PES) as a mechanism to take account and recognise the value of environmental services to society. In this arrangement some of the beneficiaries of ecosystems pay the provider for services received, and by doing so ensure the conservation of that particular ecosystem source. PES also improves rural livelihoods and thus contributes to sustainable development. Although still in its infancy, PES has been recognised as a promising new environmental policy, and developing these markets has been a central part of recent conservation efforts.

PES has been described as a method for internalising the positive externalities associated with a particular ecosystem. The success of PES schemes depends on a well-understood market for services, with a well-defined service (or specific land use which supports the service), and clear providers and buyers of the service who are both willing to enter into a voluntary transaction on transparent payment conditions, usually upon delivery of the service (Pagiola *et al.*, 2004; Wunder, 2005). In reality very few schemes fulfil these conditions.

Box 3.2. Australian water markets

Water trading in Australia was legislated in the 1980s as a demand side management approach to alleviate emerging water scarcity. The purpose of establishing regulated markets was to encourage a more efficient use of an increasingly scarce resource, by allowing water to move from low productive uses to high productive uses.

The Murray Darling Basin (MDB), which is the catchment for the Murray and Darling Rivers accounts for the majority of water trade in Australia. The MDB is home to 2 million people and extends across four states. The majority of trade is conducted within states although a pilot interstate water trading project was introduced in 1998. Water trade is conducted between irrigators once the government has announced its annual allocations depending on the availability of water supply. The system prevents over consumption and regulates the amount of water diverted from the basin in accordance with seasonal flows. In drought years the allocations are much lower to reflect the shortage in water supply. Concerns about the environmental sustainability of the basin and the unpredictability of seasonal flow patterns have led to a capping system on the volume of water diverted from the basin.

Due to the variability of seasonal allocations, entitlements can be traded on a temporary or permanent basis. A temporary transfer of entitlements allows the buyer access to the seller's water allocation for a particular season. This enables farmers to adjust to changes in supply between seasons and manage risk during times of drought. Farmers have the option to sell entitlements when prices are high or buy entitlements when prices are low. Permanent transfers allow the buyer access to the seller's water entitlement for the current season as well as all future entitlements. The majority of trade that occurs in the MDB is on a temporary basis. This is largely due to the fact that permanent entitlements are more expensive and also the uncertainty that surrounds future government allocation announcements.

Over the last year the Murray Darling Basin has been affected by the most severe drought on record. Thus farmers have become more dependent on the market to either increase their allocations to sustain agricultural output, or as a source of financial compensation. There have been several economic gains from water trading in Australia, as the transfer of water entitlements has moved from low value uses to high value uses. Large irrigators are confident that in times of water shortages, water can be obtained from the market albeit at a high price. Smaller farmers can use the market as a form of financial insurance against low productivity. Market prices have increased over the last year to reflect shortages in water supply caused by drought. In the Murray irrigation region, prices rose from a high of AUD 140 per mega litre in the 2005/06 season to a high of AUD 800 per mega litre in the 2006/07 season. The total value of water traded in this region rose from AUD 4.2 million to AUD 12.3 million.

There are some concerns about the capacity of water markets to cope with the threat of increasing water shortages and greater climate variability as a result of climate change. However, water markets in Australia are proving to be an efficient way of managing the pressures of water shortages and an effective adaptation strategy to cope with the effects of climate change. The success of the markets can be attributed to the legislative and institutional framework established by the Australian government through which trade is conducted. This ensures that water entitlements are clear, well-defined, tradable rights. Furthermore the separation of water entitlements from land ownership means the rights to water can easily be transferred, this has also allowed for a more equitable distribution of water supply. The regulatory role of the government has also ensured that over consumption of water resources does not occur at the expense of environmental degradation of the basin.

Source: Murray Darling Basin Commission (www.mdbc.gov.au); Bentley (2007).

Box 3.3. Informal water markets in India

Informal water markets have developed in irrigation communities across India as a response to both actual and perceived shortages in water supply. Informal water markets are characterised by the absence of any legislative or institutional framework through which trade is conducted. The emergence of water markets is a response by communities to problems of water scarcity at a non state, localised level.

While informal water markets exist in many regions of India, they are most developed in water scarce, irrigation communities of Gujarat, Tamil Nadu and Andhra Pradesh. Water trade in these regions is mainly conducted between large landowner farmers with access to groundwater systems (sellers) and poor farmers with very little or no access to irrigation water supplies (buyers). This exchange is reinforced by riparian rights that exist in India, which tie water rights to land ownership, as well as by the high costs of developing infrastructure to extract groundwater. Poor farmers thus rely on groundwater markets for irrigation purposes.

Groundwater is extracted via tube wells using either electric or diesel pumps. Farmers extract water in excess of what is required for their own irrigation purposes and sell the surplus locally to neighbouring farmers. Payment is made either through cash, labour or sharecropping where water is paid for by a proportion of the buyer's output.

The establishment of informal markets in India has alleviated the stress of water shortages for many irrigation farmers and led to a more efficient allocation of water resources. Water trading has led to significant gains particularly for smaller irrigation farmers, who without informal water markets would be denied access to water resources.

However, water markets in India have been developed without any legal and institutional framework and are thus characterised by high monopolistic prices, unreliable source of supply and overexploitation of groundwater resources. Access to groundwater is limited to a few large landowners who are often able to charge prices above the market rate. This has priced some farmers out of agriculture, although a more equitable allocation of water exists in the case of sharecropping. The absence of a legislative or regulatory framework has also led to the overexploitation of groundwater resources, as farmers are not limited by a capping system. Groundwater extraction by pumping has also been indirectly encouraged through subsidies for fuel and electricity.

For water markets to work effectively, clear and well defined entitlement rights to water need to be institutionalised. With the growing threat of climate change and the associated problems of water scarcity India will have to find a way to adapt to problems of drought and variability of climate. Formal markets with a legislative and regulatory framework can offer a way of allocating scarce resources efficiently whilst reducing problems of monopoly power and overconsumption.

Source: Mohanty and Gupta (2002).

The services that ecosystems provide are varied and extensive but in practice, PES schemes have mainly concentrated in four areas:

Watershed protection. Payment for watershed protection schemes are primarily undertaken at a local level and concerned with ensuring water quality and flow, sediment retention and flood reduction. Transactions between buyers and sellers are localised and usually occur at the watershed level between upstream and downstream water users. An example of watershed protection is that of hydroelectric companies who pay land users to adopt practices that will not compromise the quality of water they need to operate. UNECE (2006) has developed guidance for using PES in the context of integrated water resources management, under the Convention on Transboundary Watercourses. However, the guidelines are based more on conceptual understanding than specific experience, with only a handful of examples quoted.

Carbon sequestration. Carbon sequestration involves both the active absorption of carbon through afforestation and reforestation and the avoidance of emissions through forest conservation. Carbon sequestration plays a prominent role in the international climate debate. As such it is expected to be one of the main drivers for PES schemes, creating a link between adaptation and mitigation. Afforestation and reforestation projects are already eligible under the Clean Development Mechanism (CDM) of the Kyoto Protocol, although few projects have been developed so far. It is likely that the scope will in due course be broadened to include emission reductions from avoided deforestation and forest degradation.

Biodiversity protection. Biodiversity payments are primarily made on an international level. Payments are made to protect ecosystems that hold endangered species or genetic biodiversity. Key potential payers for these services include international pharmaceutical companies and scientific research agencies that wish to take advantage of genetic biodiversity in these ecosystems. Conservationists are also key buyers of biodiversity services in order to ensure environmental conservation and sustainability (UNEP, 2006).

Landscape and cultural preservation. Landscape and scenic beauty services are associated with upholding the cultural and aesthetic value of specific ecosystem sites. Businesses involved with ecotourism, non-governmental organisations (NGOs) and conservation groups are the main potential buyers of this service.

Most efforts to use economic approaches to promote conservation concern the forestry sector. Wunder (2005) identified 287 “PES-like initiatives” in the forestry sector but noted that very few, if any, would meet the basic criteria of a PES scheme listed above. For example, the money

often comes from donors rather than commercial user/buyers and the services purchased are frequently vague at best.

There are, however, a number of more commercially structured PES schemes. Most projects are in Latin America, with a growing number also in Africa, mainly related to wildlife conservation and parks. With support from donors, many environmental groups have been active in PES schemes for conservation purposes. An inventory developed by the Organisation of American States lists 83 examples of PES in the Americas.² Many of these are for carbon sequestration (either CDM or voluntary) or fall under formal schemes in Costa Rica and in Mexico, which concentrate, heavily on watersheds. Payments for watershed protection are also known in Colombia (see Box 3.4). An example of a private PES scheme in an OECD country is the Vittel scheme in north-eastern France (see Box 3.5).

There are also some examples of bundled services being marketed for instance in Latin America, where The Nature Conservancy purchased large areas of land, in effect, for the wide range of services that they provide. This approach can be simpler in concept but may be more costly and more complex to manage.

Box 3.4. Community-based watershed protection: the case of Columbia

In the Valle de Cauca region of Columbia a community based initiative to protect watershed services has been established by local farmers and sugar cane producers as a response to the growing levels of water scarcity in the region. The Guabas River Water User Association (Asogaubas) was set up by the community to protect upstream watershed areas. Payments for watershed protection are collected by the association from users with charges reflecting water consumption levels. The Association regulates upstream land use by either purchasing land vulnerable to soil erosion or by issuing land management contracts to upstream landowners who prevent over grazing in vulnerable areas to ensure soil stabilisation. The association acts as an intermediary between downstream users and upstream land owners, collecting fees, maintaining watershed protection and providing financial compensation for some upstream farmers.

The Asogaubas has been a success in maintaining water quality and flow and the concept has spread across Columbia. In the Rio Cauca region alone, 11 additional water-user associations have been set up to regulate water flow and quality covering 1 million hectares and including 97 000 families. Columbia now hosts several water user associations across many of its river catchments areas.

The demand for water user associations by local communities reflects the need for watershed protection in the face of growing water scarcity. With the added stress of climate change on water resources, payment for watershed protection either through the establishment of markets or water user associations will be needed to regulate and maintain water supply.

Source: Landell-Mills and Porras (2002).

2. <http://ranpa.net/PES/tProjectPES/ShowTPProjectPESTablePage.aspx>

Box 3.5. The Vittel PES scheme

Vittel (Nestle Waters), a leading brand in the mineral water industry, has developed a PES arrangement with local farmers in north-eastern France in order to maintain the quality of its water source.

Sold as a “natural mineral water” Vittel must, in keeping with French legislation, not contain any pesticides, nitrite and no more than 4.5 mg of nitrate per litre. In comparison, the maximum level of nitrate in French tap water is 50 mg, demonstrating the necessity for Vittel to protect the mineral composition of its water source. French legislation also states that mineral water cannot be treated to change mineral composition.

During the 1980s the quality of the Vittel water source had been compromised by local farming activities. Agricultural intensification in the aquifer and excessive leaching of farm land upstream had led to increasing levels of nitrate contamination downstream. In order to address this issue and conserve the quality of the water source, Vittel encouraged local farmers to change their farming practices by offering financial incentives to do so. Incentives also included technical assistance and training programmes for adapting to new farming methods. Farmers’ income levels were to be maintained at all times. By 2004 Vittel had successfully negotiated the changes and developed a mutually beneficial arrangement with farmers and an appropriate incentive structure to preserve the quality of its water source.

The Vittel PES scheme took several years to implement. Part of the complex process was the creation of an independent institution to safeguard the interests of farmers and many of the incentives provided were not purely financial. However the Vittel case study demonstrates how a privately driven initiative can help to maintain an existing ecosystem.

Source: Perrot Maître (2006).

Relevance of environmental markets and pricing for adaptation

Environmental markets and pricing – for water, forests or other ecosystem services – help to use these resources more efficiently. Prices send a signal about the scarcity of resources that incentivises owners to preserve their value and consumers to use them carefully. Markets ensure allocative efficiency. That is, they make sure resources are used for the purpose that creates the highest social welfare – whether this purpose is commercial (for example, timber logging), environmental (the preservation of species) or a combination of both (eco-tourism).

From an adaptation point of view environmental markets and pricing serve two main purposes. First, they reduce baseline stress on ecosystems, making them more resilient to cope with the added pressure of climate change. Second, environmental markets can be used to internalise, or monetise, the adaptation benefits of ecosystems.

For the first purpose it is not necessary to adjust market mechanisms specifically for adaptation. However, adaptation will be one more reason to increase the scale and scope for markets in water, forestry and other ecosystem services. Most of these schemes are still in their infancy and often still at an exploratory stage. Many more environmental markets and PES schemes are required simply for the protection of the natural environment. In this situation, the prospect of climate change may in fact strengthen the case for and urgency of schemes that would otherwise be rejected or delayed. As Easter and Zekri (2003) observed, in sectors, such as water, change usually only comes about when there is a “powerfully articulated need for reform.” The additional pressures posed by climate change only reinforce the need for finding pricing mechanisms that simultaneously address efficient allocation of water resources across sectors as well as efficient use of water within each sector.

In the case of forestry, there are additional synergies with climate change mitigation. It is likely that the development of environmental markets in the forestry area over the coming decades will primarily be driven by the desire to reduce greenhouse gas emissions from deforestation and open the forestry sector to the carbon market. Carbon sequestration benefits are a key factor that can tip the balance in favour of sustainable forestry solutions that would also help the adaptation of forest ecosystems to climate change.

While “more of the same” may be the primary adaptation response if the objective is to reduce baseline stress and signal scarcity, adjustments in the design of environmental markets may be needed if the objective is to monetise the adaptation benefits of ecosystems (that is, to achieve the second purpose mentioned above).

One of the most relevant examples in this respect is the establishment of markets for watershed services. Watershed protection services provided by forests play a vital role in maintaining both the quality of water supply and regulating water flow. Forests around key water resources provide protection against flooding as well as maintaining dry season flows. They provide protection against soil erosion, and regulate the water table, maintaining adequate levels of nutrients in water supply. These services will become more valuable as rainfall becomes more erratic and water resources more scarce. Watershed protection thus plays an important role as an adaptation strategy protecting water resources from the effects of climate change.

The protection of watershed services has traditionally been overseen by governments. However, with growing scarcity of water supply, markets are being established by the private sector to ensure water quality and reliable

supply. In most payment for watershed protection transactions, downstream beneficiaries pay upstream providers to maintain the quality of water supply/flow by avoiding changes in land use and behaviour, such as forest conversion, overgrazing and pesticide use which will compromise the quality of water for downstream users (see Box 3.4 above). Payments for watershed services thus essentially allow the redistribution of water resources by financially compensating upstream users. It is a market based mechanism that attempts to reconcile disputes over scarce water resources. As such it may be an effective adaptation mechanism against the threat that climate change poses on water resources.

Another good example of the adaptation value of ecosystems is mangrove forests. There are many examples of mangrove protection and restoration efforts and there is wide recognition of the value of mangroves (and other coastal systems) for protection against storm surges, waves and so on – a value that will increase with climate change. As a consequence of Hurricane Katrina, there has been considerable discussion of the value of the coastal systems of Louisiana in protecting New Orleans (or failing to) and efforts have been made to incorporate these values into cost-benefit analyses of options for the future of the city.

Elsewhere, natural habitats may serve as migration corridors, allowing species to move in response to a changing climate. More speculatively, the genetic diversity contained in natural systems may help in the R&D of heat and drought-resistant crops.

Despite this evident potential, there is little, if any, attention given to adaptation in the discussion of PES schemes so far. There are no examples in the readily accessible literature of PES related to these functions. Many practical problems remain, for example in terms of linking adaptation and traditional ecosystem benefits. Some coastal systems that are targeted for their biodiversity value can bring an adaptation function as an additional benefit. However, the adaptation value may not be the objective of the conservation effort and may, therefore, be neglected. Alternatively, there are areas which could have significant value in terms of adaptation but which are not biodiversity “hot spots” and so may not attract support from the conservation community.

The most important difficulty of these schemes, however, may be to find someone willing to pay for the protection provided, especially when these services are difficult to quantify and have traditionally been free. The need exists for “creative thinking” to help the ecological values to be realised in contexts where the general population is frequently very poor and where coastal management is often virtually non-existent.

Public private partnerships

The estimates of global costs of adaptation reviewed in Chapter 2 suggest that adaptation will cost several billion dollars annually in developing countries alone. The bulk of the funds – up to 60–75% according to one estimate – is earmarked for infrastructure investments. This includes both the construction and operation of dedicated defence structures, such as flood barriers, and the climate-proofing of existing infrastructure, such as roads, bridges, water systems and electric power networks. These estimates are imperfect and inaccurate, but they show just how expensive adaptation might be.

In most countries the majority of infrastructure expenditures are met from the public purse, either at the national, state or municipal level. The same is true for climate protection measures, both in terms of physical structures (sea walls, flood defences) and institutional arrangements (emergency services, disaster relief). Adaptation will thus put a considerable strain on government resources, both financial and administrative.

Faced with either operational or financial constraints (or both), governments often look to the private sector to enhance their ability to provide public services. Private sector participation or PPPs (the terms are used interchangeably here) are no panacea, but there are many cases where carefully structured private solutions have helped to overcome operational constraints, enhance performance and accelerate investment. Adaptation solutions based on PPPs would be able to draw on a considerable body of experience on how to structure private participation in infrastructure – and increasingly in other sectors such as R&D, health and education (see for instance EBRD, 2004, 2007). This section reviews the experience and draws lessons for the adaptation debate.

Forms of PPPs

Private sector participation can take many forms (see Table 3.3). Under full divestiture, the private sector takes ownership over all assets (for example, an electricity distribution network) and has control over all investment, maintenance and operations decisions (subject to regulatory oversight). Outright asset sales were the preferred form of private sector involvement in the early days, especially in developed countries. In developing countries, the private sector was usually invited to provide new installations needed to meet a growing demand. New (so-called greenfield) investment, rather than privatisation (the sale of existing assets), has been the dominant form of private sector participation in the developing world.

Greenfield investment and divestiture are particularly prevalent in energy and telecoms, where they account for more than 60% of private projects.

Table 3.3. **Types of private sector participation**¹

Type of contract	Subtype	Number of projects
Divestiture	Full	167
	Partial	596
	Total divestiture	763
Greenfield project	Build, lease and own	14
	Build, own and operate	617
	Build, own and transfer	766
	Merchant	548
	Rental	18
	Total greenfield	1 963
Concession	Build, rehabilitate, operate and transfer	381
	Rehabilitate, lease or rent and transfer	58
	Rehabilitate, operate and transfer	414
	Total concession	853
Management and lease contract	Lease contract	102
	Management contract	112
	Total management and lease contract	214
All types	Total	3 793

1. The table does not include schemes in developed countries such as the UK PFI.

Source: World Bank Private Participation in Infrastructure Database (ppi.worldbank.org).

In transport and water, where competition in the market is more difficult to introduce, the most popular form of private sector participation is concessions. Concessions are long-term contracts, often of several decades, under which the private sector assumes full responsibility for the operation and management of an infrastructure asset, including investment and rehabilitation. However, ownership remains with the state. The long contract duration makes it possible for the private partner to recoup the often sizeable investment costs. The private partner gets remunerated primarily from project revenues (for example tariff collections), although in recent schemes commercial risk has been shared more evenly between public and private partners.

The Private Finance Initiative (PFI), pioneered in the United Kingdom but now also adopted in other parts of the OECD, is an example of concessions that include both infrastructure and non-infrastructure projects. In the United Kingdom, PFI schemes have been used to build GBP 56 billion (USD 111 billion) worth of schools, hospitals, police stations, government buildings and various types of infrastructure, according

to UK Treasury statistics.³ Unlike in classic concession arrangements, the private partner does not participate in commercial success. Given their public sector nature, PFI projects rarely have a commercial revenue stream. Instead, the private operator gets paid based on performance targets.

The final form of private sector participation in infrastructure is management and lease (or affermage) contracts. These contracts are shorter in duration – typically around five to seven years – and less risk and responsibility is transferred to the private sector. The private operator typically assumes responsibility for management and operations and is remunerated according to pre-agreed performance targets. Investment remains the responsibility of the public party. Management and lease contracts have increased in popularity, particularly in weak institutional environments, where private investors have scaled down their risk appetite. Their share in private infrastructure projects has gone up from 4% in the 1990s to 10% during 2001-05 (Kerf and Izaguirre, 2007).

PPPs are also used outside infrastructure. A particularly relevant example for adaptation is public-private joint ventures on R&D, which may help to accelerate the development and deployment of adaptation technologies. Under these partnerships, government agencies team with NGOs and private companies, with each party contributing “human, physical, and financial resources to foster the generation and diffusion of innovations, new forms of technologies, and knowledge” (Hartwich *et al.*, 2007), and implicitly, with each party bearing some of the associated risks. Box 3.6 describes two examples from health and agricultural research.

3. www.hm-treasury.gov.uk/documents/public_private_partnerships/ppp_pfi_stats.cfm.

Box 3.6. PPPs for R&D

Technological innovation is crucial for reducing the costs of adapting to climate change, especially in industrial sectors and geographic areas where climate change will force drastic changes. Basic economic theory, however, shows that the private sector will under provide R&D because technological innovation has elements of a public good, as knowledge spillovers and other externalities prevent private innovators from capturing the full return on their investment. Thus, there is reason for the public sector to actively promote innovation investments. Public private partnerships, fiscal incentives, and intellectual property protection are the main methods through which governments promote R&D.

Public private partnerships are already being used in climate change adaptation. For example, in the agricultural sector developing heat and drought-resistant varieties of staple crops could make the difference between continued agricultural growth and mass food shortages. The International Maize and Wheat Improvement Centre (CIMMYT), which forms part of the Consultative Group on International Agricultural Research (CGIAR), has initiated the Drought Tolerant Maize For Africa (DTMA) Project in an effort to develop more drought-resistant varieties of maize. The project combines scientists from the CIMMYT with over 50 partners including national agricultural research institutes in Sub-Saharan African countries, advanced research institutions, NGOs and private sector seed companies. Donor organisations provide funding to research institutes that have developed 50 different varieties of drought resistant maize. The researchers then use private seed companies and community-based seed organisations to distribute the seeds to farmers in Sub-Saharan Africa, where to date over 1 million hectares of these seed varieties have been planted.

In addition to its direct effects on economic output, climate change may also significantly accelerate the spread of tropical disease. Therefore, medical research aimed at finding more effective cures and treatments could greatly improve health adaptation to climate change. However, the private sector under provides R&D for many neglected diseases, such as malaria, cholera, and tuberculosis, because the potential cures are less profitable than cures for other diseases. Public private partnerships can be effectively used to realign these research incentives. For example, the Medicines for Malaria Venture is a non-profit organisation dedicated to developing new anti-malarial drugs explicitly through public private partnerships. Launched in 1999, this venture combines the expertise of the pharmaceutical industry in drug discovery and development; knowledge of public institutions in biology, clinical medicine, and field delivery; and funding of governments and private foundations. Currently, it works with over 80 partners and more than 600 scientists in 34 countries and has now built the largest and most diverse portfolio of anti-malarial drug projects in history.

Source: www.cgiar.org; www.cimmyt.org; www.mmv.org.

Current coverage

Private companies have always been involved in the provision of infrastructure services. Much of the railways network in countries, such as the United Kingdom and the United States, for instance, was built with private capital, while France is home to some of the oldest private providers of water and municipal services. However, over time most infrastructure came under state control, and it was only in the 1980s and 1990s that private involvement in infrastructure became mainstream again. Crucially, the privatisation drive went hand in hand with efforts to split up the natural infrastructure monopolies and introduce competition in sectors, such as telecoms, electric power, natural gas, railways and water. Competition, as much as private ownership, is the key factor behind the efficiency improvements observed in many privatised industries.

Starting in the United Kingdom, private participation in infrastructure spread across the globe, including developing countries and emerging markets. According to the World Bank, almost 3 800 infrastructure projects with private sector involvement were launched in developing countries between 1990 and 2006 (see Table 3.4). Through them, the private sector made investment commitments of over USD 1 trillion. While sizeable, these commitments are, however, only a small part of total investment needs.

Table 3.4. Private sector participation in developing country infrastructure, 1990-2006

		Number of projects	Project investment (USD billion)
By region	Latin America and the Caribbean	1 202	435.2
	East Asia and Pacific	1 080	253.3
	Europe and Central Asia	740	206.5
	Sub-Saharan Africa	332	50.6
	South Asia	329	93.4
	Middle East and North Africa	110	52.3
By sector	Energy	1 481	321.6
	Transport	989	179.5
	Telecom	797	537.3
	Water and sewerage	526	52.8
Total		3 793	1 091.3

Source: World Bank Private Participation in Infrastructure Database (ppi.worldbank.org).

Private infrastructure commitments in developing countries peaked in 1997, when USD 114 billion were committed in one year. The market collapsed following the Asian financial crisis and it took until 2006 before the same level of commitment was reached again. By that time, the nature of contracts had changed. The private sector had become more wary about

emerging market risks and important lessons had been learned (see Kessides, 2004). As a consequence, recent contracts exhibit a more careful allocation of risks between public and private partners. Recent years have also seen the emergence of local private partners, although large international companies continue to dominate the sponsor list.

Latin America and East Asia have been the most attractive markets for private infrastructure projects in developing countries. The two regions account for about two-thirds of total commitments (Table 3.4). However, following a number of large telecoms transactions, Eastern Europe has recently gained ground (see World Bank, 2007). There are also a sizeable number of projects in Sub-Saharan Africa, but they tend to be smaller in size.

In terms of sectors, a majority of private infrastructure funding went into telecoms, where investment commitments are particularly large, and energy (mostly electric power). Between them, the two sectors account for over 80% of total investment commitments. The list does not include any projects that could be called dedicated climate protection investments, such as coastal defence structures. In fact in the water privatisation of 1989 in the United Kingdom, flood defence structures were explicitly excluded from the asset sale (see Box 3.7).

However, many PPP contracts contain implicit adaptation provisions. Either directly or indirectly the private partner generally assumes weather-related risks. Contracts based on service availability, for instance, which are common in the road sector, may penalise service interruption due to climate events. In this way, well-designed PPPs give an incentive to private operators to secure water supply in drought periods, keep roads safe in all weather, protect power lines against storm damage and safeguard port infrastructure from floods.

The World Bank estimates that about 6% of private infrastructure projects, accounting for 8% of investment commitments, are distressed or have been cancelled (Table 3.5). The failure rate is particularly high in the water sector where 10% of projects, representing a third of investment commitments, are in distress. Failure rates are also significant in Latin America, where many of the early projects took place, and in Sub-Saharan Africa. In general, projects would be more successful if: contracts are awarded competitively through a transparent tender, the risk allocation is well reasoned and fair, the contract allows for periodic reviews, and there is a clear conflict resolution mechanism.

There are no cases of contract failures triggered by climate events, such as a flood, drought or landslide, although the costs arising from such events

will play a role in tariff setting and might give rise to contract re-negotiations.

Box 3.7. The Thames barrier

In England and Wales control of flooding is the responsibility of the Environment Agency, an independent but government funded public body tasked with certain environmental control functions. Responsibility for flood protection includes the operation of flood defence structures. The best known of these is the Thames Barrier, the world's second largest movable flood barrier, which protects London and the Thames estuary from tidal surges and coastal flooding.

The Thames Barrier was a public project. It was undertaken by the then Greater London Council and its Department for Public Health Engineering, although design, building supervision and construction were outsourced to the private sector. Three quarters of the GBP 537 million budget (in historic prices) was raised from central government, with local taxpayers meeting the balance. Construction lasted from 1974 to 1982.

When the Greater London Council was abolished in 1986, responsibility for the operation of the barrier moved to the regional water board, the Thames Water Authority. Thames Water was privatised in 1989 and at that point responsibility for the barrier – together with other regulatory and environmental management functions – was transferred to a newly created agency, the National Rivers Authority, which in 1996 became the Environment Agency for England and Wales. The government wanted to keep responsibility for flood risk management in public hands.

Source: www.environment.agency.gov.uk.

Table 3.5. Share of private infrastructure projects cancelled or in distress, 1990-2006

		Percent of projects	Percent of investment
By region	Latin America and the Caribbean	10	12
	East Asia and Pacific	7	11
	Europe and Central Asia	3	2
	Sub-Saharan Africa	11	4
	South Asia	2	4
	Middle East and North Africa	6	2
By sector	Energy	6	10
	Transport	6	11
	Telecom	5	4
	Water and sewerage	10	33
Total		6	8

Source: World Bank Private Participation in Infrastructure Database (ppi.worldbank.org).

Relevance of PPPs for adaptation

In applying private infrastructure schemes to climate change adaptation two main questions arise. The first question is how vulnerable current and future PPPs are to climate change and how they can be climate-proofed. The second question is whether PPP schemes are suitable to finance, build and operate dedicated climate protection schemes, such as flood barriers and coastal defences.

While it is doubtful that many of the 3 800 private infrastructure contracts contain explicit adaptation provisions, it is likely that many of them expose the private partner to weather-related risks. As such they are vulnerable to climate change. This is particularly because of the long lifespan of many infrastructures over which the impacts of climate change will become progressively significant. A subjective assessment of the climate vulnerability of existing private infrastructure projects is shown in Table 3.6. The issue is most prevalent in the case of seaports, which will have to deal directly with the impacts of sea level rise, and for water utilities, which will have to manage an increased variability in precipitation and water supply. Selected other structures will be similarly vulnerable, such as coastal power stations, roads and railway lines susceptible to landslides or floods and overhead cables that might be affected by extreme weather.

PPPs are essentially about the efficient and fair allocation of risks (and rewards) between public and private partners. Climate change is just another risk factor, albeit an increasingly important one, that has to be taken into account alongside regulatory, commercial, macroeconomic and other risks. Private infrastructure schemes should be well suited to deal with this additional risk in the sense that the institutional arrangements to analyse, mitigate and allocate it are in place. At the same time, the miscalculation of risks is one of the main reasons why PPPs fail.

The best way to avoid miscalculation and failure is to recognise climate change as an explicit risk, rather than an unexpected *force majeure*. PPP contracts should spell out explicitly and in some detail, if possible, the responsibilities and expectations of each partner. For instance, the contract may stipulate certain performance standards (say, the availability of port facilities or roads; water quality and supply standards) that are to be maintained independent of climate events or until certain climate triggers are reached. This would incentivise the private operator to undertake the necessary level of adaptation.

Table 3.6. **Vulnerability of private infrastructure projects**

Sector		Segment	Number of projects	Vulnerability
Energy	Power	Electricity distribution only	124	Medium
		Distribution and generation/transmission	143	Medium
		Electricity generation	842	Low (high on coasts)
		Electricity transmission	51	Medium
	Gas	Natural gas distribution	243	Low
		Natural gas distribution and transmission	34	Low
		Natural gas transmission	46	Low
Telecom	Telecom	Fixed access only	155	Low/medium
		Fixed access and other services	205	Low/medium
		Mobile access and/or long distance	437	Low
Transport	Airports	Runway	2	Medium
		Runway and terminal	85	Medium
		Terminal	31	Low
	Rail	Fixed assets only	8	Medium
		Fixed assets and freight/passenger	67	Medium
		Freight and/or passenger	23	Low
	Roads	Bridge	38	Medium
		Bridge and highway/tunnel	54	Medium
		Highway	375	Medium
		Tunnel or tunnel/highway	9	Medium
	Seaports	Channel dredging	4	High
		Channel dredging and terminal	20	High
		Terminal	275	High
Water	Treatment	Potable water and sewerage treatment plant	7	Medium/high
		Potable water treatment plant	106	Medium/high
		Sewerage treatment plant	134	Medium/high
	Utility	Sewerage collection and treatment	7	Medium/high
		Water utility with sewerage	223	High
		Water utility without sewerage	49	High

Source: World Bank Private Participation in Infrastructure Database (ppi.worldbank.org) and authors' assessment.

Similarly, adaptation provisions may be reflected in the investment commitments of the private party. For instance, a private water utility may undertake to invest in new reservoirs as part of the concession agreement. In the case of greenfield investments adaptation may be incorporated in the

design and construction phase of a PPP. A good example is the Confederation Bridge, a 13 km toll bridge which connects Prince Edward Island and New Brunswick in Canada. The bridge was designed, built, financed and is now operated by a private consortium. The technical specifications called for a structure that is about 1 metre higher than currently necessary to accommodate future sea level rise. The anticipatory measure added a modest CAD 10 million to the cost of the CAD 1 billion project (Smith *et al.*, 1998).

Including service standards and climate risk explicitly in the contract does not imply that the private partner will assume the costs of adaptation. The cost of these measures will be reflected in the bid price for an asset and/or higher revenue expectations. For example, private operators will expect adaptation expenditures to be recognised as a permissible cost to be passed on to end users in any tariff reviews. The cost of adaptation will (and should) be shared between the government, end-users and the private operator.

In terms of the second question – whether PPPs are suitable for dedicated climate protection schemes – there are, to our knowledge currently no private infrastructure projects that explicitly provide climate protection. However, the concept is sufficiently broad and well established to extend easily to dedicated adaptation infrastructure.

The closest existing schemes to dedicated public private adaptation projects are probably the UK PFI and some of the transport schemes. As would be the case with adaptation infrastructure, the main contribution of the private partner under PFI is in the provision of the physical infrastructure (a building, a road, or a tunnel), while the actual management of the structure involves less complexity in terms of operations, client interaction, pricing and revenue collection. Moreover, there is no commercial revenue in which private partners could participate. They are remunerated from government sources based on system availability and other performance indicators.

The relative commercial and operational simplicity should make private adaptation schemes easier to implement. However, as in all private infrastructure schemes, one has to ascertain the benefit of this arrangement over a conventional model of public finance, with design, project management, construction and maintenance carried out by private companies operating under normal procurement and contracting provisions – what in the context of the UK PFI is known as a value-for-money test.

Two generic arguments were given above in favour of such schemes – efficiency in construction and operation, and the ability to finance projects outside the government budget. Of the two, the first argument is probably

less important. The same operational simplicity that makes private adaptation easier to implement also limits the potential benefit that private management can bring. Flood defences and similar projects offer limited scope for alternative designs and operations and maintenance costs are small relative to the initial capital costs. There are, thus, relatively few areas where a private operator can add value.

In contrast, the second argument is potentially very important, given the large adaptation needs in infrastructure, although fiscal sustainability constraints may impose limitations on the use of the instrument. In the absence of commercial revenues the private partner would be paid by the state and the government would commit to making these payments under the contract. These commitments, therefore, become a liability that should at least in principle be recorded in the public accounts in the same way as debt. How private infrastructure investments are treated in the fiscal accounts depends partly on their priority and economic return (see IMF, 2004a, 2004b).

These concerns point to the need for careful cost-benefit analysis and project appraisal for adaptation infrastructure. An important issue for flood defences and similar measures is the absence of a clear market demand and expression of the public's willingness to pay. While we are currently insufficiently prepared for climate change, it is easily possible that society might "over-adapt". There are countless examples of gold-plated or excessive infrastructure projects – whether publicly or privately financed.

Concluding remarks

Humans have adapted to climate for millennia, devising behavioural patterns, technologies and socio-economic systems suitable for all climate conditions from arctic cold to desert heat. It is, therefore, tempting to assume adaptation to climate change will happen automatically. In fact, much of it will, and the measures taken will be a diverse mix of operational adjustments, investments, risk sharing, location decisions and behavioural changes at the firm, household and government levels. However, for the process to be effective a raft of policy measures will be required to prepare the ground. There is a need for incentives to adapt, as well as adequate information to do so effectively.

Adaptation policy is, therefore, about much more than raising money and meeting the costs of defensive measures. Perhaps too much of the recent adaptation debate has been about costs and who should pay. This debate is important, and least developed, highly vulnerable countries in particular will need all the financial help they can get. But it is also important that this

money is spent wisely. We know from other areas of public policy – development aid, regional aid, industrial policy – that ill-conceived policies can be wasteful and in some cases counterproductive.

Since people are experienced at adapting, enlightened adaptation policy will want to tap into that expertise. It will want to promote private initiative, innovation and the unique ability of markets to turn risks into opportunities.

This chapter has provided some pointers as to how smart policy can turn private initiative into a force for adaptation. The chapter shows how a combination of markets and public policy can refine risk sharing (through innovative insurance schemes), improve natural resource management (through the creation of environmental markets) and help climate-proof infrastructure (through PPPs).

Insurance has a dual role with respect to adaptation. Access to insurance payouts can lessen the net adverse impact of climatic events on policy holders. At the same time, insurance is also an instrument for incentivising adaptations aimed at climate risk reduction. However, even this sophisticated and well-developed tool will have to be adjusted to deal with climate change. As climate damages grow and historical weather records become less reliable, insurance will become a riskier business. Risks will be exacerbated if budget constraints, inertia and cultural factors prevent people from adapting fully in the short term. As a result, insurance companies may no longer be willing to cover certain risks or may overcharge for coverage. It is likely that this will particularly affect poor households and poor countries, where uneven insurance cover is already an issue. Public policy measures will be needed to overcome these market imperfections. They could for instance take the form of publicly funded adaptation measures to bring risks down to an acceptable level. Alternatively, risks may be shared between commercial insurers and the public sector. In this case the government could subsidise the most extreme layer of risk without creating perverse incentives and impeding adaptation decisions that might be needed to respond to more systemic climate risks. Broader use of premium subsidies, however, may reduce incentives to move away from activities that become progressively less viable under the changing climate.

The need for sound management of natural resources will grow in importance under climate change. Water resources, forests and other ecosystems are already under considerable stress from pollution, overexploitation and mismanagement. Without adequate measures, climate change risks pushing some systems over the limit. Ill-defined property rights and under-pricing are at the root of poor resource management. Economic instruments, such as cost-based pricing (including environmental costs) and environmental markets can help to overcome these market imperfections.

Although still in their infancy, there is growing experience with such instruments in practice, and they can help to promote adaptation behaviour. From an adaptation point of view environmental markets and pricing – for water, forests or other ecosystem services – serve two main purposes. First, they reduce baseline stress, making systems more resilient. Second, they help to monetise the adaptation services provided by ecosystems, for example coastal protection in the case of mangroves and wetlands. For the first purpose it is not necessary to adjust market mechanisms specifically for adaptation. For the second purpose adjustments will be needed to internalise fully the adaptation benefits of natural systems. In addition, there will have to be a reliable demand willing to pay for these services.

As Chapter 2 has shown, building climate-proof infrastructure is likely to be the most expensive part of adaptation and will put considerable strain on the administrative and financial capacity of governments. Experience elsewhere shows that well-designed PPPs can help to overcome operational constraints, enhance performance and accelerate investment. In applying PPP schemes to adaptation two main questions arise. The first is how PPPs need to be adjusted to deal with climate change. PPPs are all about the allocation of risks. As such they should be well suited to deal with an additional, if as yet ill-defined risk. Many PPPs already contain implicit adaptation provisions. However, climate change has to be recognised as an explicit rather than unexpected risk. The PPP contracts need to spell out explicitly the responsibilities and expectations of each partner, including in terms of adaptation. The second question is whether PPP schemes are suitable to finance, build and operate dedicated climate protection schemes, such as flood barriers and coastal defences. There are as yet no the dedicated adaptation PPPs. However, the concept is sufficiently broad and well established to extend to dedicated adaptation infrastructure. In addition, PPPs may play a role in R&D and the search for better adaptation technologies.

Setting up insurance schemes, environmental markets, PPPs and similar schemes will be a considerable challenge to public policy. Much further work is needed to refine the concepts, work out details and set up pilot schemes. A key ingredient will be good climate information at the local level – a condition that is in most cases not yet fully met. Preparatory work will also be required to build technical and institutional capacity, particularly (but not only) in a developing country context, and to reach out to stakeholders. Adaptation to climate change as a public policy challenge has only just emerged.

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Economic Aspects of Adaptation to Climate Change

COSTS, BENEFITS AND POLICY INSTRUMENTS

Edited by **Shardul Agrawala** and **Samuel Fankhauser**

Climate change poses a serious challenge to social and economic development. Efforts to reduce greenhouse gas emissions need to move hand in hand with policies and incentives to adapt to the impacts of climate change. How much adaptation might cost, and how large its benefits might be, are issues that are increasingly relevant both for on-the-ground projects and in international development co-operation and negotiations contexts.

This report provides a critical assessment of adaptation costs and benefits in key climate sensitive sectors, as well as at national and global levels. It also moves the discussion beyond cost estimation to the potential and limits of economic and policy instruments – including insurance and risk sharing, environmental markets and pricing, and public private partnerships – that can be used to motivate adaptation actions.

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