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Climate Change Adaptation

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ECONOMICS OF ADAPTATION TOOLKIT

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FOREWORD

Climate change, including climate variability, is having detrimental effects on human well-being across the developing world. Increasing temperatures, changing rainfall patterns, rising sea levels and increasing frequency and intensity of extreme weather events are adversely affecting ecosystem functioning, water resources, food security, infrastructure and human health. Moreover, these climate change effects are predicted to become increasingly severe. Conscious of the need to counter climate change impacts which are already being felt in the region, as well as the need to prepare for more severe impacts in the future, countries are eager to understand how national budgets can be applied to address the challenges of climate change in the most cost effective manner.

The Capacity Building Programme on the Economics of Climate Change (ECCA) was a three-year programme, comprised of a series of technical trainings interspersed with mentor-assisted in-country applied work to enable trainees from 10 countries in Asia to master key economic concepts and tools for adaptation planning and decision-making. Launched in October 2012, ECCA addressed a consensus reached during a regional stakeholder consultation that a more comprehensive approach to mainstreaming climate change risks into planning processes was needed to ensure economically-efficient climate change strategies at the sectoral, sub-national and national levels. The innovative program aimed to identify gaps in capacity development needs in an area that is critical for helping countries formulate national adaptation plans and access climate finance.

The programme targeted mid- and senior-level public sector officials from planning, finance, environment and other key ministries responsible for formulating, implementing and monitoring climate change programmes. They were grouped into multi-disciplinary country teams. The country teams participated in four regional workshops, which provided training on theory and the practical application of cost-benefit analysis, and introduced participants to forecasting, modeling and sectoral analysis, looking into country-specific institutional development plans, within the context of ongoing and new initiatives. Each regional training was interspersed with fieldwork application, guided by economists who served as mentors to the country teams. Together, these two principal programme components provided building blocks to guide participants through the theory, principles and application techniques of economic analysis.

Country teams have now begun reporting the results of their training and in-country application. This toolkit was prepared for the consideration of decision-makers and country teams together with their country team economics mentors and ECCA expert staff. With this training and hands-on experience, it is expected that the members of the country teams will play pivotal roles in mainstreaming climate considerations into future development planning, ultimately seeking to institutionalize these important analytical skills.

The training activities, together with the country reports and regional report (which compiles the individual country reports to take a view of regional considerations in the agriculture sector), in conjunction with the ECCA Toolkit has contributed to a key area of technical assistance required by countries, as per the United Nations Framework on the Convention of Climate Change's (UNFCCC) guidelines for countries on the National Adaptation Plan (NAP) process - a process established under the Cancun Adaptation Framework (CAF) to help countries identify their medium- and long-term adaptation needs.

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EXECUTIVE SUMMARY

The Economics of Climate Change Adaptation initiative is supported by UNDP, in collaboration with USAID's Adapt Asia-Pacific programme. It is a capacity building programme aimed at strengthening the skills and knowledge base of technical officers in Ministries of Planning and Finance as well as line ministries including Environment, Agriculture, Water, and Public Works, for example, on the economics of adaptation as it relates to medium- and long-term national, sub-national and sectoral development plans. Support is provided to also strengthen skills in applying techniques from the economics in evaluating adaptation investment projects.

This toolkit is one of the outputs of the programme after two years of working with technical officers in the various ministries across the countries represented in the ECCA programme. During this period, UNDP and USAID delivered a structured training programme targeting technical officers at the national and sub-national level to estimate the economic costs and benefits of climate change impacts, as well as adaptation options that were relevant for the agriculture sector in the region. The toolkit reflects the work undertaken in the region and the results of the analysis of survey data that was explicitly collected for the purpose of better understanding the impacts of climate change on smallholder farmers in the region. The toolkit also provides an insight into the potential impact of climate change on poverty across the region.

Understanding the economic costs and benefits of climate change at the micro and sectoral level requires detailed information of the sector and the potential vulnerabilities. While there have been numerous ad hoc reports aimed at understanding the impact of climate change on different economies, detailed data that is required for rigorous evaluation and understanding of the impact and optimal adaptation strategy is typically lacking. This toolkit aims to address gaps in knowledge and provide tools for doing so.

Photo Credit: USAID/UNDP

ACKNOWLEDGEMENTS

The Capacity Building Programme on the Economics of Climate Change Adaptation (ECCA) program in Asia is part of the collaborative work of UNDP, USAID's Adapt Asia-Pacific Programme, Yale University's School of Forestry and Environmental Studies, and the Asian Development Bank. Under the direction of Pradeep Kurukulasuriya (UNDP), Babatunde Abidoye (UNDP and University of Pretoria), Robert Dobias (Adapt Asia-Pacific Programme) and Robert Mendelsohn (Yale University), the programme benefited from technical inputs from Mariana Simoes, Claudia Ortiz, Mari Tomova and Mark Tadross (UNDP), Ali Akram and Namrata Kala (Yale University) and Benoit Laplante (ADB).

This toolkit was prepared by Ali Akram (Yale University), Martijn Gough (UNDP), Robert Mendelsohn (Yale University) and Pradeep Kurukulasuriya (UNDP) with reviews from Babatunde Abidoye (University of Pretoria), Brianna Hunt Ficcadenti (USAID Adapt Asia-Pacific), Janine Twyman Mills (UNDP), Jessica Troni (UNDP), and Robert Dobias (USAID Adapt Asia-Pacific).

Our thanks extend to the UNDP Country Teams involved in the ECCA programme for their involvement, and for providing insight into their respective country portfolios.

The findings of the study were discussed at the 5th Asia-Pacific Climate Change Adaptation Forum on October 17-19, 2016.

Finally, the contribution by AECOM International Development implementing the USAID Adapt Asia-Pacific Programme is acknowledged.

ACRONYMS

AEZ	Agro-ecological Zone
APSIM	Agricultural Production Systems Simulator
CCCMA	Canadian Centre for Climate Modeling and Analysis
CGE	Computable General Equilibrium
CO_2	Carbon Dioxide
CPM	Cotton Production Model
DIVA	Dynamic and Interactive Vulnerability Assessment
EBHOM	Energy-based, Hydropower Optimization Model
EPA	Environmental Protection Agency
GCM	Global Circulation Model
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GTAP	Global Trade Analysis Project
IAM	Integrated Assessment Model
IPCC	Intergovernmental Panel on Climate Change
CBA	Cost-Benefit Analysis
ECCA	Economics of Climate Change Adaptation
FAO	Food and Agriculture Organization
PPM	Parts Per Million
NEM	North East Monsoon
NO_X	Oxides as Nitrogen
RCP	Representative Concentration Pathways
SRES	Special Report on Emissions Scenarios
SREX	Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework on the Convention of Climate Change
US	United States
VOCs	Volatile Organic Compounds
Water-AIM	Watershed Allocation Impact Models
WHO	World Health Organisation
WTA	Willingness to Accept
WTP	Willingness to Pay

INTRODUCTION

The extent of future climate change will depend on the global level of Greenhouse Gas (GHG) concentration in the atmosphere. Given the difficulties of overcoming the hurdles of a global agreement on acceptable levels of emissions and the cost of driving those emissions to zero abruptly, it is reasonable to expect that GHG concentrations will increase above present levels. Further, because there are long lags between emissions and climate change, climate is going to continue to change solely because of historic emissions, even if there are no more emissions in the future. Consequently, every society must consider investing in climate change adaptation, no matter what future mitigation might take place.

Scientists predict that both the average local weather (warmer and wetter or dryer) and possibly the weather variability (frequency of dry periods, heavy precipitation, heat waves, frost, cyclones etc.) will change. The impact of these changes will have on human societies will depend on how effectively individuals, firms and governments adapt to the expected and unexpected manifestations of these climatic changes. Of course, the more mitigation that is accomplished, the less the climate will change, however adaptation will be needed even if future mitigation is effective.

Adaptation is not targeted at reducing GHG emissions nor does it alter the change in climate. That is the role of mitigation. The role of adaptation is to alter the consequences associated with the changes in climate. To put it generally, climate change adaptation will reduce the damages or losses associated with climate change. However, in some circumstances adaptation will also carry potential benefits by seizing on new opportunities brought about by climate change.

Since climate change impacts depend on a combination of local climate, how the climate changes, and other local conditions (geographic, natural, social and economic), impacts will vary greatly across space. As such, optimal adaptation will also vary across space. While mitigation is inherently global in scope, adaptation is predominantly local. On the positive side, this means adaptation will not suffer from the global coordination problems plaguing mitigation. Individuals, firms, and even local governments have an inherent incentive to adapt and make themselves and the people they represent better off. On the other hand, it means that adaptation will be very complex, varying a great deal across the landscape.

Determining which kinds and levels of adaptation are efficient for a given area is not always an easy task; for any action to be efficient, the benefits must exceed the costs. Economic analysis is particularly helpful for identifying efficient adaptation, as well as deciding what actions to take, and when and where to take them.

This toolkit assumes adaptation requires both short-term and long-term actions to properly adapt. There is an important distinction here because one needs different tools for making short-term versus long-term decisions. Short-term decisions involve adapting to the current climate, and any near-term changes in the climate, with appropriate specific adaptation actions and investments. Long-term decisions, on the other hand, require sector-wide studies that are capable of evaluating a great range of large non-marginal changes in climate into the distant future.

To understand what immediate projects are worth undertaking in the short term, cost-benefit analysis (CBA) is a useful tool for economic decision-making. To understand, however, how an entire system will adjust over long time periods and multiple scenarios, one will need to engage in partial and general equilibrium analyses of the key sectors that must adapt.

The present Economics of Climate Change Adaptation Toolkit is designed to help decision makers determine the best path for long-run adaptation. While elements of the CBA process for decision-making regarding short-term adaptation will be examined occasionally throughout the toolkit, the tools presented here focus mainly on supporting long-term decision-making for adaptation.

The toolkit will:

- Explain what is meant by the phrase "economic analysis of adaptation";
- Present a general process for sector-wide economic analysis to support long-term adaptation decisions and describe in detail the steps to be taken along the process;
- Describe a number of existing tools, methods and models used in long-term economic analysis of key climate-sensitive sectors, including the data required, the needed skills, the expected results, and the strengths and weaknesses of each; and
- Provide relevant examples and case briefs demonstrating how to apply these tools.

This document targets mid-level technical government staff and individuals in local institutions responsible for economic assessment of adaptation projects and programs. Senior members of ministries responsible for assessing the quality of proposed projects and programs that include climate change adaptation objectives will also benefit from this toolkit.

The methods presented can be used to evaluate adaptation actions in both developed and developing economies. However, the focus of this document is on developing countries, where adaptation is most needed and most challenging. Low latitude countries – most of which have emerging or least developed economies – are predicted to bear over three-fourths of global climate damages. Developing countries will not only bear the burden of climate change impacts, at the same time they have the lowest capacity to adapt and the greatest barriers to adaptation. The low latitudes will likely be the focus of both current and future adaptation efforts.

CHAPTER 1

DETERMINE LEVEL OF STUDY

1.1 THE ECONOMIC ANALYSIS OF ADAPTATION

Determining what adaptations are efficient is not always an easy task. From an economic perspective, benefits must exceed costs for a specific type or set of adaptation actions (or activities) to be efficient. Economic analysis is particularly helpful for identifying efficient adaptations and determining what actions to take, when an adaptation should be undertaken, and where they should take place. Economic analysis applies to both private and public adaptation and can help both the private sector and governments determine "what", "when" and "where" adaptation actions should occur. There are of course hurdles to identifying what actions to take. Analyses must be undertaken to evaluate different types of projects to understand what factors determine costs and benefits. Long term decisions that involve large changes over many decades must be evaluated sector by sector. Until the world becomes experienced at making these decisions, there will be a lot of uncertainty.

This is especially true of decisions to adapt to changes in the distant future. Distant climate change, especially at the local level, is likely to remain uncertain. Distant socioeconomic conditions are also uncertain. In contrast, short-term adaptations tend to be more straightforward. Short run decisions simply require people to adapt to the climate they are experiencing now. Although weather remains uncertain, the climate over the next decade is relatively well understood. There is much less uncertainty involved in reacting to observed climate changes. There remain questions about optimal strategies of adaptation, but most changes in the short run are not radical, they tend to be marginal adjustments of current decisions. There are consequently two broad issues facing decision makers.

1.2 INTRODUCING A GENERAL PROCESS OF ECONOMIC ANALYSIS FOR MAKING DECISIONS

One broad issue facing decision makers is how to make changes over a long time horizon to address the long-term problem of living in a very different future climate. The second question is what concrete actions should be taken right now. The two questions are related but not the same. The long-term plan requires foresight and a gradual but steady transition from one state to another. Long-term investments into long lasting capital must be continually adjusted as climate unfolds. Looking forward, it is planned as a consistent path towards a new climate. However, looking backwards, after the fact, it will look like a series of jagged steps in a dynamic adjustment (not always in a consistent direction) as the climate unfolds and the future climate becomes clear. In addition, society must adjust its short run decisions to match the climate it actually finds itself in. This is more of a reactive process aligning management to the climate that is revealed at each moment. Assuming that climate itself changes in jagged steps, this reactive process, looking backwards will also appear to be jagged. This short run adjustment process is just an on-going effort to live in the climate at each moment.

This toolkit assumes adaptation requires both short term and long-term tools to properly adapt. There is an important distinction because one needs different tools to make the short-term decisions from the tools required for the long-term decisions. The short-term decision requires that one adapt to the climate at the moment and to near term climates with appropriate specific actions and investments. These decisions require cost benefit analysis of concrete individual projects. Understanding the long-term decisions requires sectoral studies that are capable of evaluating large non-marginal changes into the distant future. The range of possible climate changes in the distant future is much greater. We consequently divide this toolkit into two different sets of tools. To understand what immediate projects are worth undertaking, cost benefit analysis is promoted as a useful tool for economic decision-making. To understand how an entire system will adjust over long time periods and multiple scenarios, one will also need to engage in partial and general equilibrium analyses of the key sectors that must adapt.

1.3 SHORT-TERM VS. LONG-TERM DECISION-MAKING FOR ADAPTATION

There are two sets of adaptation projects for developing countries that are worth pursuing. Short-run projects that address problems with the current climate are worth doing now. Undertaking such projects is consistent with adapting to a path of climate change in the long run. At every moment, with a changing climate, it will be important to adapt to the present climate of that moment. A second set of adaptive actions (projects) must focus on capacitating economies, be it at the national or local level, on managing long-term change in climate, including associated risks and uncertainties.

By focusing on the current problems with climate, one is adopting a policy that is climate sensitive. This policy acknowledges that decisions should change as the climate changes. Decisions must be updated to match the climate currently being experienced. That does not mean we will still be adjusting in 2030 to the climate in 2015. But rather that in 2030, we must adjust to the 2030 climate, just as we presently adjust to the current climate now. This approach is straightforward because we know a lot about the climate we currently face. The weather remains uncertain, but observations of recent years help us to understand our present local climate. It makes sense that individuals and firms, as well as governments, would take measures to make sure that management is updated to current conditions.

Another advantage of focusing on short-term adjustments to current climate conditions is that benefits would materialize in the short-term. We would not have to wait long to be rewarded for making improvements. A policy of adapting to present climate is also a pre-condition to adapting to future climate. It paves the way to a gradual transformation from the present equilibrium to a new, still unknown equilibrium. By enhancing resilience to present climatic conditions, the capacity to adapt to future climate change will also increase. Adaptation to present climatic conditions also enhances development, a powerful tool for long-term adaptation. In fact, sometimes it may be difficult to distinguish between development and adaptation. Any effort that increases income and welfare given current conditions could be justified on either count. Projects of adaptation to present climate will build capacity, institutions, markets, information and know-how that will be of extraordinary importance when dealing with future climate. Learning how to adapt to present climate will start a process of adjustment that will last into the future.

Although decision makers need to choose concrete adaptation projects in the near future, they also need to be aware of long-term needs that will appear as climate changes dramatically in the distant future. Long-term climate change may require dramatic changes in particular sectors. Current adaptation projects may do very little to prepare countries for these long-term adjustments because they are too far into the future to address today. However, it is helpful for countries to be aware of possible future outcomes as they develop plans for future development and growth. Although these analyses are more useful for medium and long-term planning rather than current action, they help map a path of action over time from current choices to future outcomes.

One of the features of distant future climate changes is that they may require relatively non-marginal (i.e. large) changes in vulnerable sectors. In order to understand how economic systems react to large changes, one must build and analyze the results produced by system wide models. If there were large changes throughout an economy, one would need a macroeconomic model of all the sectors in an economy to model the outcome. However, if only certain sectors will experience a large change, it is often sufficient to model individual sectors, such as health, agriculture, etc. In each case, these models are explored to understand what they say about large-scale adaptations that may be required in each sector depending on how climate changes far into the future.

Cost benefit analysis is a powerful tool for assessing which specific choices (in the form of distinct projects) should be undertaken in the short run (in the here and now). There is a significant and well established economic literature on the theory and practice of cost-benefit analysis (Mishan 2007; Brent 2008).

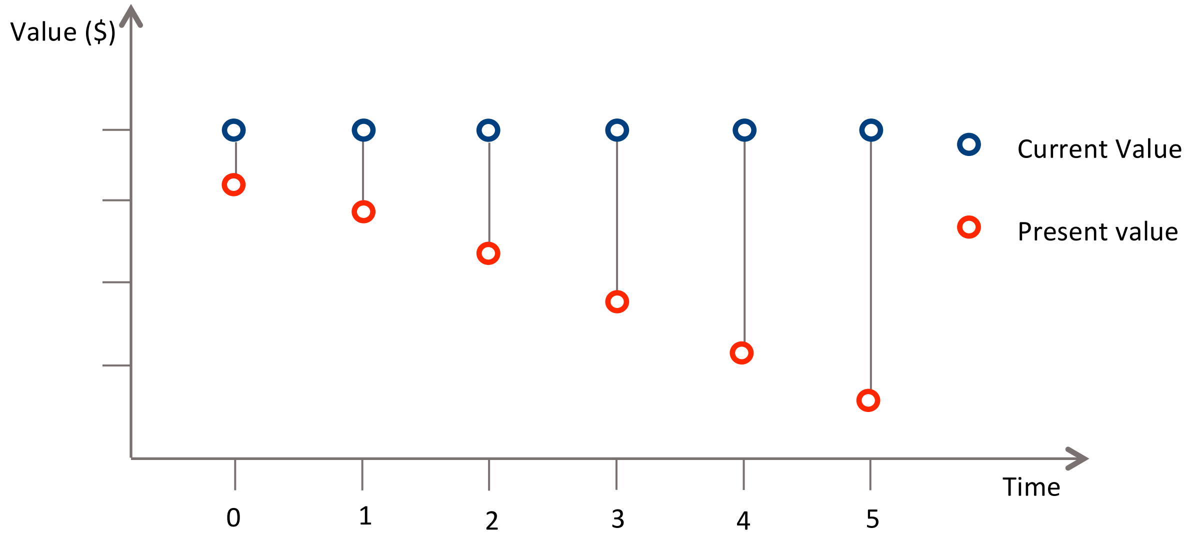
One major hurdle to conducting cost benefit analysis is quantifying both the cost and the benefit of the projects in question. All types of direct and indirect costs should be included whether they involve the time of the agent, out of pocket costs, or costs imposed on other people in the society but not borne by the project budget. Similarly, all direct and indirect benefits should be included whether they are market goods with observable prices or nonmarket goods that are not bought and sold in markets at all. For example, projects designed to protect ecosystems or human health may have minimal effect on the economy but they can nonetheless improve the quality of life for people. These benefits must be valued even if they have no observable prices.

Short-term adaptation projects should take into account current climate. As climate changes, it is important that decision makers are aware of how their current climate has already changed. This is not a question of forecasting future climate but rather keeping up to date records of the current climate. Although this may seem trivial, a great deal of adaptation will be done just by keeping firms, individuals, and government decision makers aware of the current climate as it changes. If decision-makers are aware of the current climate, economic theory indicates that people will take the current climate into account in their decision-making calculus. People will weigh the costs and benefits of doing different actions and move towards the personal actions that yield higher net benefits. Over time, people will adapt to their current climate just as they have adapted to other local conditions they face. As climate evolves, people will change their short run decisions to match the climate they are experiencing. In this context, maintaining an up to date local weather system is an important component of climate adaptation.

Cost benefit analysis of long-lived capital projects requires taking a longer-term perspective. One must not only look at current costs and benefits but also how these cost and benefits may change over the length of the project. Long-lived projects consequently require not only the current climate but also forecasts of how climate will change. Specifically they require knowledge of how local climate might change over the lifetime of the project.

In order to value the stream of costs and benefits of a long-lived project, economists typically compute the "present value" (PV). The value of things that occur in the future are discounted so that they have the same value as things that occur today. The price of time is the discount rate. The discount rate would be zero if society did not care when costs and benefits occur. In practice, the discount rate is determined every day by financial markets that balance current, near term, and distant future values. The discount rate revealed in these international transactions are market interest rates. They are called "nominal interest rates" when they also reflect inflation and they are called "real interest rates" when inflation is taken out. The real long-term interest rate is about 4%. The concept of PV is not a new concept but one which is used commonly in any calculation that must take into account costs or benefits over time. Briefly, the value of a good/service in each time period is weighted so that it is equivalent in value to that good or service at the current moment (e.g. today). The weighted values are then summed across the length of the period in question. The figure below represents this concept. Income, goods, and services received further into the future all have a lower value compared to getting those services today. The present value of the good or service falls with time. For example, imagine that a job offers to pay you at the end of a year for all the work you do during that year. Is that the same as being paid every two weeks? What if the job offers to pay you your salary in ten years? The value declines the longer you must wait to receive it. The same applies for individual goods and services. The value of time is the same for all goods and services. The value of time has a small effect on short-lived projects that delay just receipts a year or two but it has a large impact on projects with long-time spans. Rewards received 10, 30, or 50 years later are much lower valued. Of course, the same applies to costs. If the cost of a project can be long delayed, the cost is valued less. The present value takes into account the fact that distant future outcomes are worth much less than current outcomes.

Figure 1: Weighted values across time



The value of time is measured in the market place by the interest rate. The interest rate is determined in a global investment-savings market that weighs consumption today against consumption tomorrow. It is not an arbitrary value that can be selected independently for each project but rather a cumulative choice that society makes for all projects (climate, private capital, and public capital) simultaneously.

There have been many critical essays written about the interest rate being too high, that society should weight future consumption more closely to current consumption (e.g. Stern 2007). Implicitly, they are arguing that people should sacrifice more of their current quality of life in order to assure future generations of an even higher quality of life. Such low interest rates are possible if people sacrificed more current consumption for future consumption and therefore saved more. We simply do not observe societies making this choice either individually or collectively through their governments. Forcing people to have lower interest rates causes a society to invest in more capital. Some of this capital would go into hospitals, schools, and the environment, but some of this capital would

INTEREST RATE

The interest rate is the price of time determined by the global investment market. The interest rate balances the demand for capital by investments against the supply of capital by savers. The interest rate equilibrates the return of the marginal investment against the payment to the marginal savings. It reflects both the marginal value of time for savers who are foregoing current consumption for future consumption as well as the marginal opportunity cost of investment.

Cost benefit analysis uses a discount rate as the internal price of time to evaluate costs and benefits in the future. If the interest rate is the discount rate, the project can be compared with alternative investments around the world.

However, some normative analyses argue there are ethical reasons to use lower discount rates than the interest rate. They argue society should care more about distant future consumption relative to current consumption. Lower discount rates make projects with distant future benefits relatively more attractive. However, these ethical arguments generally apply to all investments and not just specific investments. The implication is that society should subsidize savings so that people simply consume less today. If one does not alter savings behaviour, using a lower discount rate only on selected projects, implicitly acknowledges that the rate of return of the selected project is less than other available investments.

include more weapons, more factories, more shopping malls, more cars, and more homes as well. If this additional capital is not chosen but rather is imposed on people, it becomes an added burden that must be carried by the current generation. More importantly, it must also be carried by each subsequent generation, making every generation worse off. It is therefore not clear there is an ethical argument for lower discount rates.


Photo Credit: USAID/UNDP

Another argument for lower discount rates comes from concerns about intergenerational equity. However, income per capita has been growing since the start of the industrial revolution. If this continues, each future generation is richer than the last generation. Lower interest rates therefore imply that the poorest generation (the current one) must support the future richer generations. The ethical justification of this argument is also not obvious.

More typically, critics recommending a low discount rate simply are advocates for having a lower discount rate for their pet projects. The argument is not really about time or equity at all but simply about subsidizing whatever capital project the person happens to favour. One point that is absolutely clear is there is no justification to treat time differently for specific goods and services. Using different discount rates for different projects is inefficient.

Estimating costs and benefits for long-lived projects is not an easy task. Because one must value outcomes in the distant future, they are inherently uncertain. Not only is future climate hard to predict in any one location, but many other factors such as prices, technology, and economic growth are difficult to pin down in distant future periods as well. One must, for example, predict the decay rate of the capital, changes in demand and supply for the service provided, and other changes in background conditions. As the consequences of a decision lengthen, the value of those consequences become more uncertain. The long-term consequences of long-lived projects tend to be more uncertain than short-term projects, holding all else constant. Climate change is not the only source of uncertainty but it does increase the riskiness of climate sensitive long-term projects, making them less attractive.

Cost benefit analysis focuses on the net outcome to society. It weighs the sum of the benefits against the cost. Cost benefit analysis tends not to weight how the costs and benefits are distributed within a society. All costs and benefits are treated equally. In contrast, most political processes give the distribution of both the costs and the benefits a large weight. How project costs and benefits are distributed across individuals is often very important to political systems. Some systems favour specific individuals or groups in which case they are looking at whether the benefits to this specific group are greater than this group's costs. For example, local officials may care primarily about the costs and benefits to their locality. Other systems might favour projects whose costs and benefits affect particular families or groups within a society. Cost benefit studies can reveal the distribution of costs and benefits but the analysis itself tends to ignore these distributional issues. The public decision maker must decide what weight to give distributional issues.

Cost benefit analysis is a frequently used tool in assessing different investment options and, one of a range of factors for deciding on whether to go ahead with a specific investment or not. It is not appropriate, however, for making large programmatic changes to the economy or specific sectors. Long-term climate adaptation may well require some sectors to make fundamental and transformative changes in their activities (for example which crop to grow in agriculture) or the capital stock (how much cooling or heating is needed in buildings). These changes can be large enough to shift supply and demand functions. Prices, instead of being fixed as they are for small projects, will change in response to the program itself. System wide analyses of sectors and sometimes even entire economies will become necessary to understand large-scale measures.

COST-BENEFIT ANALYSIS OF CLIMATE CHANGE ADAPTATION

Cost benefit analysis allows a policy maker to determine whether it is "worth" implementing a particular climate adaptation project. Not all adaptation projects will yield the same benefits minus costs; a policy maker should push for the selection of a project only if benefits exceed costs.

Cost benefit analysis is not without its challenges:

1. Valuation techniques may not exist for certain types of benefits (especially environmental) and sometimes costs as well.
2. Costs and especially benefits occur over a long period of time.
3. Both costs and, especially, benefits can be uncertain.

Long-term analysis of climate change over decades requires the use of sectoral economic models and analytical tools. One must understand how an entire economic system will adjust in response to a transformative policy or approach. For example, agronomic research might suggest that a large change in temperature would reduce yields of maize. Cost benefit analysis is perfectly suitable to discern what an individual farmer in a specific place might do in response to a small change. However, only a sectoral model of agriculture could determine the global response to a large change. Globally, there could well be a reduction in maize supply but there would also be an increase in the price of maize and adjustments by many farmers around the world. Some farmers would abandon maize entirely for a new crop other farmers will suddenly start growing maize. A cost benefit analysis in a specific place could not anticipate these system wide changes. Sectoral models are needed to capture these system wide effects and evaluate these large-scale changes. Adaptation is a big part of the response of these sectoral models.

1.4 PUBLIC VS. PRIVATE ADAPTATION

Economic analysis applies to both private and public adaptation and can help both the private sector and governments determine "what", "when" and "where" adaptation actions should occur. Private adaptation is defined as the changes a decision maker will make to benefit him/herself alone. For example, a firm may alter how it produces a product if it gets warmer and the change will lead to higher profits. If the firm benefits from making the change, it has an incentive to do it. If the costs of the change, however, outweigh the benefit, the firm will not adopt the change. When the benefits of the adaptation accrue to the decision maker, the decision maker has an incentive to adopt the adaptation. Private adaptations will be efficient. In a world of perfect information and rational behaviour private adaptations will be adopted at efficient levels. Private actors will take actions leading to net benefits for themselves and avoid actions with net costs that make themselves worse off. The government does not have to provide additional incentives to encourage private individuals to adopt efficient private adaptation. In fact, governments must be careful not to distort incentives for private adaptation that would encourage individuals to make inefficient choices. Rather the government must set the right incentives so that private adaptation is efficient. Each household must examine the relevant local conditions to determine how best to adapt to their own local situation. It is difficult for governments even at the local level to know what is best for each household - private adaptation is generally best left to private parties.

However, there are conditions when even private adaptation may not be efficient due to imperfect information, credit constraints and institutional constraints. For example, some actors may lack access to knowledge about climate change or their adaptation options. In this case, governments should focus on informing people how climate is changing and what adaptation actions may help. Actors may not have access to credit. In this case, governments may want to help make sure banking services are available at market rates. Actors may have limited property rights. For example, people who share common property may lack incentives to invest in protecting that shared asset. In this case, governments may want to reinforce individual rights. If adaptations involve large externalities, private individuals may not face the right incentives to choose socially efficient actions. In this case, governments may want to price pollution and other externalities through taxes or regulations. Local and national governments, as well as international organizations, should work to reduce these private sector barriers or distortions to efficient adaptation.

In contrast to private adaptation, public adaptation is defined as a response to climate change that involves a public good. Public goods benefit many people simultaneously. For example a radio or television broadcast is a public good. The benefits of public goods are shared whereas the benefits of private goods are not. Private goods such as a shirt are consumed individually whereas public goods are consumed collectively. Sectors that tend to involve public goods include conservation, public health, and flood control. They tend not to be market sectors because markets have trouble delivering public goods efficiently. More intuitively, the benefits of public goods accrue to society at large. Typical examples of such public decisions include public infrastructures such as canals, dams, bridges, and sewage systems. For such social investments, the private sector rarely has sufficient incentive to provide the goods because they cannot capture its entire social value. These "public goods" consequently fall upon the government to provide. The aggregate benefit of each of these investments is the sum of what all the beneficiaries are willing to pay. Governments must often take charge when the investment or good is public in nature.

Public adaptations are responses to climate change that involve a public good, a good whose benefits are shared across many people. For example, changes in precipitation might require changes in flood protection for large numbers of people in a watershed. Warming may increase the damage from pollution emissions leading to higher ozone levels for many thousands of people. Changes in climate might require a different set of protection for an ecosystem enjoyed by many. Changes in mean sea level might require a coastal flood response for everyone along a coastline. A public health measure may protect an entire population from endemic disease caused by climate change. Markets struggle providing public goods because many share the benefits. The group of beneficiaries rarely can coordinate enough to purchase a response for themselves. It is not worth it for individuals to act alone. Governments are better prepared to make these decisions because governments can readily weigh the social benefit to all their people against the cost. Unlike private adaptation, public adaptation depends on active government involvement. Public decision makers will therefore need to develop skills and methods to identify and support efficient public adaptations.

SUMMARY OF KEY MESSAGES

- **Economic analysis provides a useful framework to study adaptation to climate change.**
- **The goal of adaptation should be to maximize social net benefits. For efficiency, the benefit of each adaptation project must exceed its cost.**
- **Cost-benefit analysis is a powerful tool to guide project level investments in adaptation. If resources are limited, they should be invested only in the most efficient projects.**
- **Climate proofing, reducing the impacts of climate change to zero, is often inefficient because it leads to many projects whose cost far exceeds their benefit.**

Photo Credit: USAID/UNDP

CHAPTER 2

SELECT A METHOD

2.1 A GUIDE TO EFFICIENT ADAPTATION

Adaptation is the set of actions that individuals, firms and governments undertake in response or in anticipation of climate and climate change. Climate includes climate norms defined as mean weather variables over a thirty-year period. However, climate also includes the distribution of weather events over time. For example, the variance of weather events, extreme events such as droughts, floods, and heat waves and the probability distribution of storms are all part of climate. Climate change, in turn, can refer to changes in the mean as well as changes in the variance or the probability of specific types of storms. More is understood about changes in climate norms than changes in variance or extreme events. Both variance and extreme events are more difficult to model and more difficult to measure, making it harder to determine how they are changing or are likely to change. The same is true about changes in sea level. Most research has focused on changes in the mean sea level, although it is also possible that changes in storms could lead to changes in the maximum tides observed.

As changes in mean temperature, precipitation, and sea level are better understood, early research on adaptation tended to focus on these climate changes. Adaptation, however, can be undertaken to all climate changes, not just changes in climate norms. If scientists predict or start to observe more variance in temperature, for example, adaptation can be designed for this change as well. Similarly, if scientists predict there will be a change in storm behaviour, society can adjust to this prediction. Adaptation includes all actions that can make us better off in a new climate no matter what the change in climate happens to be.

The overarching goal encouraged by economics is to choose only the adaptation options that increase net benefits. That is, taking into account the benefits and costs of each action, welfare maximization would require that only options that make one better off be implemented. Efficient adaptation includes all adaptation options that deliver an economic benefit greater than the economic cost. If resources are limited, the most efficient set of actions should include only those that maximize overall economic welfare.

One source of confusion in the literature is whether or not to "climate proof" society. We follow the World Bank definition that "climate proofing" a system attempts to eliminate all the damages caused by climate in that system. In general, it is not practical to climate proof society, as weather will continue to cause some damages no matter what actions we take. More importantly, it is not a sensible goal to try to eliminate all the damage caused by climate change. In order to eliminate every last damage that climate change causes would force society to invest in many responses whose cost far exceeds the value of the eliminated damage. For example, society would not invest, for efficiency purposes, in a flood control program that costs US$10 billion if it only eliminates US$1 billion of flood damage. Such projects are counterproductive. They increase the burden of climate change rather than reducing it. In this example, a US$1 billion burden becomes a US$ 10 billion burden on society.

Society needs to be more selective about the adaptations to undertake. Society should fund adaptations only when the damages avoided are greater than the cost of the adaptation. This is just common sense. Society should only undertake climate adaptations if they make society better off. That is, there are net benefits only when total benefit exceeds total cost.

In this publication, we discuss two broad and related concepts. As climate change evolves over a century and beyond, decision makers need to predict how a society can gradually make transformational changes in their various economic activities and capital stock to adjust to possible paths of climate change. System wide tools are needed to understand these large long run sets of adjustments. At the same time, at any one moment in time, society must also determine concrete responses or actions to implement at each moment in time. Society also needs tools to choose which specific choices make sense at that moment.

2.2 THE METHODS AVAILABLE: AGRICULTURE

2.2.1 INTRODUCTION

Agriculture is very likely the sector that will be affected most by climate change. Agriculture is also a very important sector for most developing countries. Therefore efficient adaptation to climate change in agriculture is extremely important. This chapter presents two methods that can be used to study efficient adaptations to both future and present climate. A third method can be used to study how farmers respond to unexpected weather events.

2.2.2 THE AGRO-ECONOMIC METHOD

The Agro-economic method combines a model that simulates the growth of crops (crop model) and an economic model. Most of the economic models used do not allow crop switching. The important exception to this is the mathematical programming models of Adams et al. (1990; 1995) for the United States, which have examined crop switching as an efficient adaptation. The crop model provides a detailed description of the relationship between crop yields, weather, carbon dioxide and other inputs, such as fertilizers. Variation in the quality or quantity of production inputs, including climate is transformed by the crop model in a variation of yields. Therefore, crop models can be used to test the effectiveness of alternative adaptation measures. With information on the relationship between inputs and outputs and on prices of inputs and outputs it is possible to select the mix of inputs and outputs that maximizes profits using an economic model. If the exercise is repeated simulating a change of climate it is possible to select the mix of adaptations (changes of both inputs and outputs) that maximizes profits.

An advantage of crop models is that they can predict the impact of carbon fertilization. Higher levels of carbon dioxide allow plants to keep their stomata closed, increasing plant drought resistance and yields. All agronomic experimental studies show that carbon dioxide (CO2) fertilization greatly mitigates the impact of climate change and in some cases it generates an overall positive net effect on yields.[1] A survey of 430 studies reveals that yield increases on average by 33 percent for a doubling of CO2 concentrations from 275 to 550 (parts per million) ppm.[2]

In practice, the evaluation of long-term adaptations would proceed as follows:

1. Scenarios on climate change, of physical impacts and of socio-economic change are prepared for the region under exam;
2. The agro-economic model is calibrated to reflect local conditions; if the area under exam is large, the model must be calibrated on many sites to reflect geographic, climatic and socio-economic differences;
3. The scenarios are used to estimate the impact of climate change without any adaptation;
4. The scenarios are used to estimate the impact of climate change with adaptation; and
5. The change in net revenue per hectare of agricultural land measures the benefit of adaptation.

AGRO-ECONOMIC MODELS

These models combine a crop model of each of the major crops with an economic model of agriculture. The most common agro-economic models that have been used around the world fix crop choice and inputs and simply examine changes in yields as climate changes (e.g. Rosenzweig and Parry 1994; Parry et al. 2004 Iglesias et al). The changes in yields are then interpreted as changes in supply in the economic model, which then predicts crop prices. When adaptations are tested in these simple models, they test across the board increases in inputs that are intended to increase yields. The researchers do not test for endogenous adaptations that increase the net revenue of each farmer. These simple models do a fairly poor job of capturing adaptation because they generally ignore it and when they include it, they do not model efficient choices.

A more sophisticated agro-economic model that relies on mathematical programming was created for the United States (Adams et al 1990; 1995). This model allows farmers to choose the crop that maximizes net revenue. Farmers consequently do exhibit limited endogenous adaptations in this model. The model shows that farmers switch crops in response to yield and price changes. However, the choice of inputs is held fixed in this model. This sophisticated model is calibrated for the United States but must make assumptions about exports and imports. Global data is not available to build such a model for the world yet. There are consequently few examples of such a model outside the US.

Figure 2 provides an example of how the assessment often works with a crop model. The figure presents the relationship between yields per hectare and average temperature for two different crops. Both relationships are estimated using the crop model. Let us assume that the price and costs at which farmers can sell both crops is the same so that yield and net revenue are equivalent. With the present climate at T, crop A maximizes yields and profits. That is, at temperature, T, YA(T)>YB(T). As temperature rises from T to T'

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[1] See for example Cure and Acock (1986).
[2] See Kimball (1983).

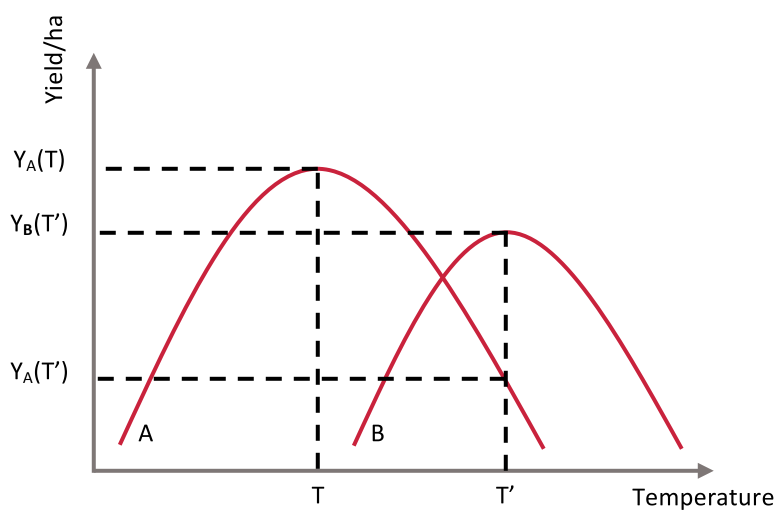
the yield from crop A declines while the yield increases for crop B. The impact of climate change without adaptation would be equal to the loss of productivity of crop A. The crop model would predict a drop in yields from YA(T) to YA(T').

However, the drop in yields holding crops constant overstates the actual loss that a farmer in this situation would have. AS temperature increases from T to T', the farmer is better off if they switch from growing crop A to growing crop B. Switching from crop A to crop B is an efficient adaptation. The benefit of changing crop variety would be measured by the difference in net revenues at temperature T'. Given our assumptions above, we are measuring this change by a change in yields. The actual loss the farmer will have is the difference between YA(T) and YB(T'). The net benefit of the adaptation is YB(T')-YA(T'). Because this is a gain, the farmer will make this change all on his own to make them better off.

Agro-economic models can also be used to study adaptation to current climatic conditions. In this case the process would proceed as follows:

1. The observed local mix of inputs and outputs is compared with the optimal mix predicted by crop models for areas with similar geographic and climatic characteristics;
2. The difference between the observed profits and the highest possible profits provides a measure of the burden of socio-economic constraints on the profitability of agricultural land; and
3. The effect of alternative policies that reduce socio-economic constraints (i.e. adaptations) on profits is tested using the agro-economic model.

Figure 2: Relationship between yields per hectare and average temperature for two different crops



Notes: Hill-shaped curves reflect effect of temperature on the net revenues of crops A and B. At temperature T, crop A has higher net revenues than crop B. At temperature T', crop B has higher net revenue than crop A. Because it maximizes his net revenue, the farmer will choose crop A at temperature T and crop B at temperature T'. If a crop model assumes the farmer stays with crop A at temperature T', it will overstate the actual damage the farmer will have. The adaptation, in this case, is crop switching (from A to B) and the net benefit from crop switching is Y_B(T')- Y_A(T').

Although one could argue that farmers are not likely to adapt perfectly, it is extremely unlikely that farmers completely fail to change management practices to increase their net revenues. Also, farmers in developing countries will maximize the value of production, net of production costs.[3] There is in fact growing evidence that farmers around the world have adapted their farming practices to their current climate.[4] Government agencies may want to provide farmers with information about efficient adaptations but it is not clear that there is any need for government agencies to induce farmers to change their practices. It is also not clear that crop models are well suited to predict how changes in management practices would improve net revenues in the face of climate change. That is, it is not clear that crop models can be used to predict what management adaptations are efficient.

Agro-economic models have been used by research centres, government agencies and international organizations to study the impact of climate change on agriculture at global and macro-regional level.[5] However, agro-economic models are somewhat limited in their ability to study adaptation. Generally, the large-scale impact studies using crop models have done a poor job of identifying efficient adaptation (with the exception of the mathematical programming models which have captured crop switching). The models have assumed a limited amount of adaptation, often without evaluating whether they are efficient. This is a key weakness of the agronomic approach: it fails to properly account for adaptation.

As the crop model is constructed from experimental evidence, to apply the model in the field, it must be calibrated to local conditions. The agronomists must measure weather and other variables and then determine the parameters of the model – for each crop variety – that reflect site-specific conditions in order to reproduce local observed yields. For each crop and each location, the model must reflect local soil characteristics, local management practice, water availability, and solar irradiance. The adjustment (calibration) of the model to the local characteristics requires a considerable amount of resources to be accurate.

Due to cost constraints, experiments cannot be done on every crop. Therefore agronomic models tend to focus only on the major crops: maize, rice, soybeans, and wheat. Fruits and vegetables that may be more appropriate for warmer locations are not modelled nor are important subsistence crops such as millet and tubers. The crop models may provide accurate estimates of what happens to major crops but not accurate estimates for agriculture as a whole. Countries with specialized agriculture that does not include the major grains may find that the crop model approach is not appropriate. For this reason there have been few applications of agro-economic models to adaptation studies.

Also due to cost constraints crop models are calibrated to only selected locations. Therefore to produce models for other locations the model must generalize effects across many crops and locations from a limited set of sites. Such extrapolations can be done in several ways. One possibility is to rely on Food and Agriculture (FAO) agro-ecological zones (AEZ) that identify homogeneous soil-climate states across landscapes. The assumption is that ecosystem types identify homogeneous AEZs and that the AEZs therefore reflect homogenous levels of crop productivity. By calibrating crop yields to each AEZ zone, one can extrapolate yields across the landscape.

3 See the work of Bardhan and Udry (1999) of profit-maximizing behaviour in developing countries.
4 Kurukulasuriya and Mendelsohn (2008); Seo and Mendelsohn (2008a); Seo and Mendelsohn (2008b); Wang et al. (2009).
5 For examples of studies that use this method see, among others, Adams et al. (1990), Adams et al. (1995), Rosenzweig and Parry (1994), Reilly et al. (2003).

The second major weakness of agronomic models is their reliance on the accuracy of climate and water availability predictions. Technically a crop model examines weather in every day of the growing season. In order to predict yield from a crop model, the daily weather must be entered in the model. In order to predict future yields, one has to introduce the future daily weather predicted by climate models. However, climate models cannot predict the daily weather of local areas with any accuracy. Therefore the accuracy of the yield prediction inherently rests upon the accuracy of daily weather predictions. One practical solution used by agro-economic models is to shift the current weather distribution using future mean climate scenarios. However, this method might poorly describe future climate if the variability of weather events changes with respect to the present.

Crop models also need good data on water availability, which depends on rainfall patterns where crops are grown but also on underground water reservoirs and groundwater availability from rivers, lakes and artificial canals. Changes in water availability and water cost are difficult to predict without a full water sector model. In places where irrigation plays a large role in agriculture, the crop model should be used in conjunction with a full water model that integrates hydrological and economic elements that affect water availability and cost.

METHOD RECAP
THE AGRO-ECONOMIC METHOD

What You Will Need

1. Data:
   a. Climate data i.e. 30 year historic values for temperature and precipitation across the landscape.
   b. Future climate predictions for the region(s) you are studying (available from the IPCC).
   c. Variables required calibrating each crop model. These can be relatively straightforward measurements like precipitation, temperature, and yield to more complex and expensive measurements such as soil hydraulic properties. Each crop model has specific requirements.
2. Integrated crop modelling and economic optimization software. Crop modelling software is typically crop specific e.g. Cotton Production Model (CPM) or soybean simulation model (GLYSIM). Economic optimization software needs to be taking the results of the crop model and predict outcomes such as the Agricultural Production Systems Simulator (APSIM).

What You Need to Do

1. Set up and make sure your agro-economic model works i.e. calibrate it to work with existing climate conditions.
2. Run the agro-economic model for the predicted climate to determine the kinds of crop and input choices will be best.

The Results

1. The model should be able to tell you the kinds of adaptations that yield the best cropping outcomes given the predicted change in climate.
2. By modifying the constraints in the model you can determine what adaptations are cost effective. For instance, you could theorize an investment in irrigation, which increases the amount of water available to crops in the model and can determine the impact of that adaptation by running the model.
3. To calculate the change in farmer welfare, you will first need to run your agro-economic model for current climate conditions and then re-run for predicted climate conditions. By taking the difference between the two you can get a sense for the change in output and farmer welfare.

2.2.3 CROSS-SECTION ECONOMETRIC MODELS THAT ESTIMATE CROP-YIELD FUNCTIONS

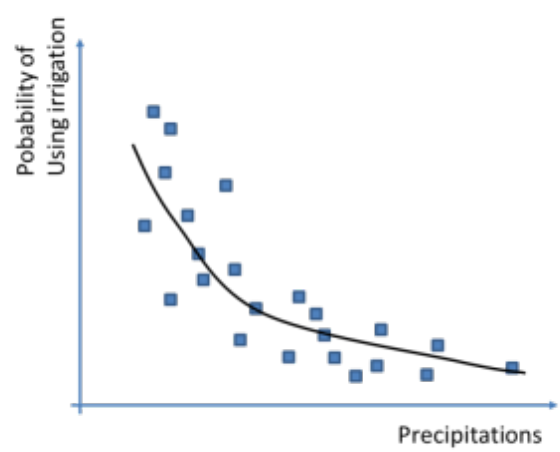
It is also possible to model crop outcomes by studying the outcomes directly. Economists use cross-section econometric models to estimate the relationship between farmers' production decisions and climate. The models rely on the assumption that farmers have adapted to the current climate they live in. They have chosen which outputs and inputs in order to maximize their net revenue. By observing the choices of farmers in different climatic conditions, it is possible to estimate the efficient response of farmers to those different climates. That is, by looking at farms across space, one can see how they have adapted to each climate zone in current use. This is a cross sectional method and not an intertemporal one. It is not looking at the dynamics of how farmers change as climate change. Rather it is comparing equilibrium outcomes from one climate to the next.

Econometric methods allow researchers to separate the influence of climate from the influence of other factors and thus provide a precise measure of how climate affects farmers' decisions. For example, Figure 3 illustrates a hypothetically observed relationship between precipitations and the probability to use irrigation across different regions. Areas with low precipitations use irrigation in agriculture with higher probability than areas with more rain. Local conditions however vary for many reasons, not only for the amount of rainfall. The econometric model is used to attribute the variation in the probability of using irrigation to climate only, separating out the influence of other factors.

Cross-section methods estimate optimal agronomic practices by observing the behaviour of farmers instead of using crop models. Therefore, cross-section methods require detailed data of the decisions of farmers and the resulting outcomes across climate zones. The approach cannot be used within a single climate zone because it needs to observe how farmers make different choices in different climates.

The cross-section econometric models do not need to use a trial-and-error process to find the efficient set of adaptations. Presuming that farmers have learned to adapt to their current climate, the observed current behaviour reflects adaptation. The observation of farmers today reveals what is efficient under the present climatic conditions. The adaptations that current farmers have made are efficient because each farmer maximizes net revenue given the current climate constraints they face. The method observes the outcome of the cost-benefit analysis that each farmer has privately done. By using information on present adaptations to climate change the model can predict what profit-maximizing farmers will do in the future.

Figure 3: The Observed and Estimated Relationship between Precipitation and the Probability to Use Irrigation

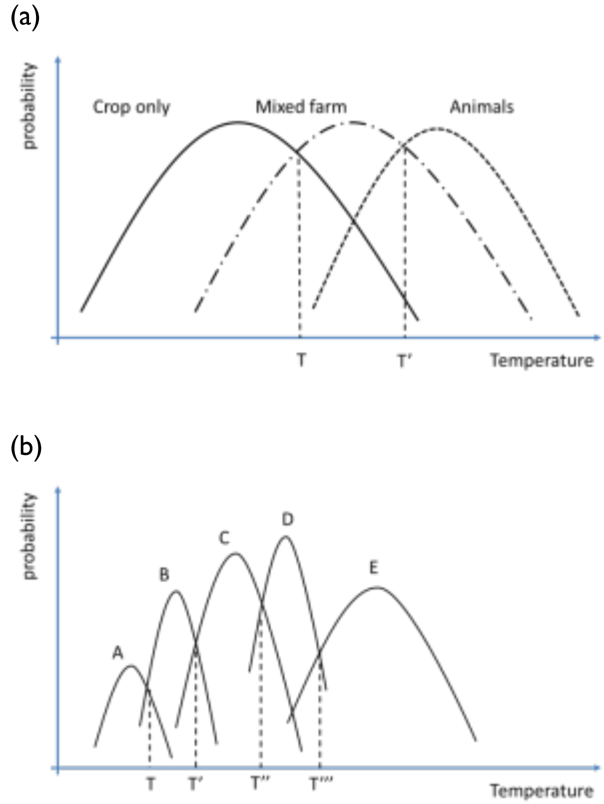


Notes: Dots indicate the observed combination of precipitations and the probability of using irrigation in agriculture. The solid line marks the estimated relationship between precipitations and probability of using irrigation.

The "structural Ricardian model" is a cross-section econometric method used in many studies of adaptation to climate change. The idea of the structural Ricardian model is simple: farmers face a sequence of decisions when they organize farm operations. A first decision is about the farm type. Farmers can use farmland to produce only crops, to keep land as pasture or have a mix of crops and animals. A second important decision is about irrigating or not. The farmers then choose what crops to grow and what animals to raise.[6] Farmers' decisions will be influenced by climate and by many factors. By separating the influence of climate variables from other drivers of farmers' choices it is possible to estimate how climate affects farmers' decisions.

Panel (a) of Figure 4 provides an illustration of how different temperatures might affect the probability of having different farm types; panel (b) displays the estimated probabilities of planting crops as a function of temperature. All curves depicted in Figure 4 describe observed efficient responses of farmers to the climatic conditions and other constraints. Those curves can be used to estimate how farmers will likely react to a change of the current climatic conditions. For example, it is possible to estimate what is the probability that farmers choose different crops or different farm types if temperature increases. The difference in net revenue between the adaptation and the no adaptation case is the benefit of adaptation.

Figure 4: The Structural Ricardian Cross-Section Model



Notes: Panel (a) describes the probability of investing in a farm type given the temperature level. As temperature increases, farmers switch from cold-loving to heat-loving farm operations. Farmers switch from crop-only farms to mixed farms to animals-only farms at temperatures T and T', respectively. Cross-section evidence provides hints on adaptation measures that farmers will take when temperature will increase. Panel (b) illustrates the probability of planting different crop types (A-E) as a function of temperature. Empirical evidence reveals that farmers will switch from crop to crop as temperature increases or precipitation changes. Empirical estimates of the probability with which some crops are adopted under a certain climate provide information on how farmers will likely adapt in the future.

[6] See for example Seo and Mendelsohn (2008a,b), Kurukulasuriya and Mendelsohn (2008) and Wang et al. (2010). See also Kala, Kurukulasuriya and Mendelsohn (2012)

In practice, the evaluation of long-term adaptations would follow these six steps:

1. Scenarios on climate change, of physical impacts of socio-economic change are prepared for the agricultural land under consideration;
2. The optimal response functions, how farmers change decisions as climate changes, are estimated using cross-section econometric methods;
3. The net revenue each farmer would earn given the crop and inputs chosen and the climate is estimated;
4. The climate and the socio-economic scenarios are used to estimate farm net revenue assuming no adaptation (current choices of inputs and crops);
5. The climate and the socio-economic scenarios are used to estimate net revenue allowing efficient adaptations by the farmers; and
6. The benefit of different adaptation choices is measured by comparing the net revenue with and without adaptation.

For some choices, the net revenue of the farmer already includes the cost of the adaptation. For example, the cost of fertilizer or pesticides is already measured in the net revenue function. In such cases, the model is measuring the net benefit (benefit minus cost) of making the adaptation. However, in other cases, the farmer may have to make a capital investment that is not part of annual net revenues to make the adaptation. For example, the farmer would have to invest in irrigation canals for irrigation or possibly different machinery to change crops. These costs are not included and the analysis is just measuring the annual benefits.

The structural Ricardian model also provides useful information to guide adaptation to current climatic conditions. Observed production decisions of farmers can be compared to those observed in regions, countries or continents with a similar climate but with higher productivity of agriculture. The comparison might reveal socio-economic and technological constraints that local farmers face. Public agencies could provide support to relax those constraints and foster agricultural productivity.

The use of cross-section econometric methods is possible only if there is enough climate variation in the sample under analysis. The cross sectional approaches consequently require data from across large areas such as entire countries or even continents. This variation of climate provides a snapshot of how farmers might adapt to climate change. For example, climate change scenarios for the period 2080-2099 generated by 14 Global Circulation Models (GCMs) for the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenario (SRES) A2, predict an average summer temperature increase in the United States equal to 5 °C (average of all models). The present difference between the hottest and the coldest county in the United States during summer across the United States is 23 °C. If summer temperature increases by 5 °C in Illinois, farmers will experience the same temperatures that farmers have today during summer in some parts of Texas.

One pitfall of cross-section methods is that they cannot measure the effect of CO2 fertilization on farmers' choices because the amount of CO2 in the atmosphere is the same all over the world and the econometric model is unable to measure the effect of higher CO2 concentrations.

Another issue that has been raised in the literature is that the cross sectional models generally cannot measure the effect of price. At any one moment, every farm in the cross section faces similar prices. This means that price variation is not one of the omitted variables potentially biasing results. However, it also means that the cross sectional method cannot determine how choices would change as prices change.

A third issue in the literature concerns how to include irrigation. There is no question that irrigation raises net revenues in places that it is adopted. Irrigation is also a choice by farmers (it is not exogenous). Finally, evidence suggests that irrigation alters the climate sensitivity of crops. One should not use the climate sensitivity of irrigated crops to predict what would happen to rainfed crops as climate changes.

Another potential limitation of the cross-section econometric methods occurs if climate and unmeasured variables are highly correlated. In this case, some of the effect attributed to climate may be due to the "omitted variable". It is consequently important to measure as many of the primary influences of productivity as possible so they can be included in the analysis as controls.

If data is available for more than one year, the cross sectional model can be estimated using panel data methods that control for time-varying omitted variables. For example, if one can track both net revenue and indicators of economic activity over time, it is easier to isolate the influence that the climate has on net revenue (Massetti and Mendelsohn 2012a,b). A second possible solution is to focus only on random weather shocks that are not correlated with unobserved characteristics of farmers (Deschenes and Greenstone 2007). All the time-invariant characteristics are controlled in a "fixed" coefficient and therefore it is not necessary to measure them with precision. However, as discussed in Method 3, "fixed effect" intertemporal models allow studying the influence of weather on farmers' decisions but not of climate, which limits the utility of those models.

Finally, a third limitation of cross-section models is that the model may not predict outcomes out of sample, beyond observed levels of climate today. For example, one may do a cross sectional analysis across farms existing in temperatures from 10 °C to 20 °C. Predictions of what would happen to farms at 25 °C may not be reliable. Of course, this limitation applies to all methods.

Photo Credit: USAID/UNDP

METHOD RECAP
THE CROSS-SECTION ECONOMETRIC METHOD

What You Will Need

1. Data:
   a. Farm level agricultural production data (this can be found in a large cross-sectional survey), specifically:
      i. Yields produced by a farmer per unit land and price per unit yield for each output
      ii. Total costs incurred by a farmer per unit of land
      iii. Total net revenues generated by a farmer per unit of land
   b. Environmental data such as soil type, topography (e.g. slope and altitude) that can be associated with each of the observations in the cross sectional survey.
   c. Climate data i.e. 30 year average values for seasonal temperature and precipitation.
   d. Future climate predictions for the region(s) you are studying (available from the IPCC).
2. Geographic Information System (e.g. ArcGIS).
3. Statistical software package (e.g. STATA).

What You Need to Do

1. Start by calculating current net revenue per unit land (e.g. $/acre). Net revenue is the total value of output per unit land minus the total cost of inputs for that unit of land.
2. Associate your climate data and environmental data with the plots of land for which you determined net revenues. There are a few ways to do this but geographic information system (GIS) software may be useful for the task. It could be that a particular plot is not close to a given climate measurement (there are a limited number of weather stations in any given territory), so you may need to first interpolate climate values between weather stations and then associate your plot of land to a given climate value.
3. Use your statistical software package to regress net revenue per unit land on the climate and environmental variables you associated with each plot.

The Results

1. You should now have regression coefficients provided by your statistical software that tell you essentially how much a unit increase in a climate variable will shift net revenue per unit land.
2. If you know how much the climate (temperature and precipitation) in a given region will change, you will be able to use your results to predict the loss or gain in agricultural net revenues per unit land.

2.2.4 INTERTEMPORAL METHODS

A crucial assumption in cross-section methods is that the econometric method can perfectly separate the effect of climate from the effect of other factors in determining farmers' choices. However, measuring with precision all characteristics of a given agricultural site is extremely difficult. For example, some key soil properties might be omitted or measured with error. These "omitted variables" might be correlated with climate and there is the risk to confound the effect of climate with the effect of the omitted variables. In this case the effect of climate on farmers' decisions would be measured with error.

In order to avoid this problem, the literature suggests using an intertemporal model in which inter-annual variations of weather are used to estimate farmers' decisions instead than using long-term climate.[7] Only variables that change over time are used to estimate the sensitivity of agriculture to climate conditions. This is a clever technique that eliminates the influence of factors that affect land values but are constant over time. Omitted variables that do not change over time – like soil properties – would not be included in the analysis.

However, this technique has drawbacks. The most important is that climate can no longer be the main variable of interest. By definition climate is a long-run average of weather in a particular place. Climatic changes develop over longer periods of time (decades to centuries) as opposed to weather changes (minutes to hours). Therefore this method estimates the impact of unexpected weather shocks on farmers' decisions rather than the long-term influence of climate.

[7] See Deschênes and Greenstone (2007) and the response of Massetti and Mendelsohn (2012a).

Intertemporal econometric methods can be used to assess the impact of transitory unexpected events on farmers' choices – e.g. the amount of water used for irrigation, planting and harvesting dates, animal management, use of fertilizers. This is indeed an important aspect of adaptation to present and future climate. Farmers will always suffer from unexpected harmful weather events. It is therefore important that they adopt the most efficient techniques to protect themselves in case of bad weather outcomes.

It is important to stress that intertemporal methods should be used to study emergency responses only and not long-term adaptations. They are suited to study how farmers react to a sudden drought, not how they take anticipatory adaptations to unexpected weather events. Anticipatory adaptations to average weather variability should be studied using cross-section methods, because the long-term variability of weather does not change from year to year, it is part of climate. In some cases long-term and short-term adaptations are necessarily linked. A farmer that reacts to a sudden drought by irrigating crops has anticipated the need of irrigating by investing in irrigation. Therefore short-term responses provide some information on the long-term adaptations. In some other cases anticipatory and long-term adaptation is instead not needed: changing planting and harvesting dates can be a short-term reaction to observed climatic conditions.

Therefore intertemporal methods provide useful information on adaptation to current and future weather shocks but cannot be used to study how the long-term average mean and variability of weather affect decisions on important farm operations – e.g. farm type, irrigation capital, machineries, buildings.

In practice, the evaluation of short-term responses to weather variability would proceed as follows:

1. A scenario of future weather variability and a socio-economic scenario are prepared;
2. The optimal response functions of farmers are estimated using an intertemporal econometric model;
3. The weather variability scenario and the socio-economic scenarios are used to estimate the impact of future variability on farmers' choices;
4. The profits of farmers with and without adaptation are compared to get an estimate of the benefit of the adaptation methods.

The method could also be used to promote efficient adaptation to present unexpected weather shocks.

Observed responses of farmers to weather variability can be compared to those observed in regions, countries or continents where similar weather shocks have occurred with minimum profit losses. The comparison would reveal if local farmers face socio-economic and technological constraints. Public agencies could provide support to relax those constraints to foster farmers' emergency responses to unexpected weather shocks

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STUDYING EXTREME WEATHER EVENTS: HEAT WAVES

Heat waves also affect agricultural output. Crop-models and econometric models show that high temperatures even for only a few days can reduce crop yields, keeping everything else constant. A set of econometric studies based on weather fluctuations show that yields of corn, soybeans and cotton in the US decrease sharply when the number of days with a high temperature above 30°C increases. Since daily average temperatures above 30°C are quite rare in the US, the impact on yields can be attributed to heat waves (Schlenker and Roberts 2008). The same method was applied to major crops grown in Africa (Schlenker and Lobell 2010). Studies of extreme temperature impacts on yields can be used to learn if farmers in warmer locations have adapted to higher weather temperatures more than farmers in relatively cool areas. Schlenker and Roberts (2008) find that the yield-temperature relationship is the same in different locations of the US. This reveals the existence of threshold effects that might limit adaptation to extreme weather events, as the climate gets warmer. Animal farms have taken precautions to reduce the impact of heat waves on animals by installing fans and spraying animals when temperature increases above a given threshold.

All methods that are used to estimate the impact of short-term weather fluctuations on farm activities can be used to reveal the adaptations that farmers that suffer lower losses have implemented. It must be stressed that these kinds of studies should be used to study adaptation to extreme events and random weather fluctuations, not to long-term average climate change.

METHOD RECAP

THE INTERTEMPORAL METHOD

What You Will Need

Similar in form to the cross-section econometric models that estimate crop-yield functions except that the data requirement is of a long run panel data set.

Data:

1. An agricultural production panel for the region being studied, specifically:
    a. Total output produced by a farmer per unit land and price per unit output
    b. Total costs incurred by a farmer per unit of land
    c. Total revenues generated by a farmer per unit of land
2. Weather data over the period of study.

Otherwise, data requirements are largely the same as in the cross-sectional method.

What You Need to Do

1. Largely the same as before, except that instead of associating climate norms with the area of study you will associate changes in weather over time to the area of study. Again, GIS software may be useful for the task.
2. Use your statistical software package to regress net revenue per unit land on the weather and environmental variables you associated with each plot.
3. Note that you will need to use panel regression methods.

The Results

You should now have regression coefficients provided by your statistical software that tell you essentially how much a unit increase in a weather variable will shift net revenue per unit land.

2.3 THE METHODS AVAILABLE: FORESTRY PLANTATION

2.3.1 INTRODUCTION

Forests provide a wide range of services: they supply timber, they host ecosystems and protect soil from erosion, and they offer amenity values and recreation. Climate change will affect forests by changing the optimal growing conditions of trees and the habitat for the whole ecosystem that is hosted and surrounds forests.

This section deals with managed forests and the impact of climate change on timber supply. Forest plantations cover about 3 percent to 7 percent of total global forested area but the area is growing rapidly over the years (FAO, 2010). Section 2.6.4 deals with the impact on recreational values and Section 4.2 discusses method to estimate the non-market value associated to impacts on ecosystems.

Managed forests are not the same as agricultural crops. They have a much longer rotation period than most crops and so are quite slow to adapt. The literature has consequently explicitly modelled the dynamic of forests whereas they often rely on comparative static models of agriculture.

2.3.2 FOREST PLANTATION MODELS: ECOLOGICAL AND ECONOMIC APPROACHES

Ecological forest models describe how geographic variables, soil characteristics; climate and forest management practices affect the optimal mix of trees and other production choices. Therefore forest models are well suited to study adaptation to climate change. By comparing the value of yields and the cost of inputs under different management decision forest model provide useful information to assess the benefits of alternative adaptations. As crop models, forest models include the fertilization effect of CO2.

Forest models show that moderate warming is going to be beneficial for plantation forests. New areas that are too cold to plant trees will become available. The altitude at which trees can be planted will also increase. CO2 fertilization is going to accelerate the growth of trees. Excessive heat will however be harmful because it will reduce growth, it will spread pests and pathogens, and it will increase the probability of fires. Extreme weather events, like windstorms and droughts may also damage forests.

Ecological forest models share the same pitfalls of crop models: they are data intensive, require careful calibration and do not include minor tree species that could become valuable with warming.

Forest models can be used to study the impact of climate change and of different management practices on forest yields. However, without an economic model, it is impossible to assess if the adaptations are efficient. Coupling an economic model and a forest model is however not as simple as for crop models because the economic model must have a long-term horizon.

Timber markets have a long-time horizon. It takes several decades for a tree to grow up to the point in which the economic return is at its maximum and it is efficient to cut it. A model that studies the forestry sector must thus stretch over a long time period. Static models are not suitable to study the forestry sector. Economists refer to long-term models in which decision makers take optimal decisions over the entire time horizon "dynamic models". Dynamic models can be built either under the assumption of perfect foresight – agents are able to perfectly predict what is going to happen in the future, especially the consequences of their actions – or under the assumption of imperfect foresight – economic agents take decisions on the basis of information available over a limited time-horizon. Perfect foresight models deliver solutions that are more efficient than those obtained by imperfect foresight models because they can use more information. However, perfect foresight models might overestimate the predictive capacity of economic agents. In the forestry sector imperfect foresight might lead to miss some benefits of climate change or to miss future negative impacts. Adaptation can be inefficient in imperfect foresight models. Therefore, both solution modes should be tested when studying future impacts and adaptations.

DYNAMIC MODELS

To study economic problems that involve the element of time we use dynamic models i.e. models that explicitly include time in them. This is quite unlike the static cross sectional analysis when looking at climate change impacts and adaptation in agriculture.

Sohngen and Mendelsohn (1998) developed a dynamic economic model of the US timber market in which planted species and management options are endogenous. The model thus provides information on the optimal adaptations to climate change. Sohngen, Mendelsohn, and Sedjo (2001) extend the US timber model to all world countries and study the global implications of climate change, taking into account global trade effects on demand and supply. The economic module of the Sohngen et al. model is coupled to a biogeochemical model, which computes what happens to the biological productivity of each ecosystem type, and to a biogeographic model, which predicts how eco-system types shift across space.

By using a future climate change scenario it is possible to study how the growth of each ecosystem type is affected and how ecosystems will shift across space. Yields for each timber type are taken from the literature and assumed to change proportionally to the change of productivity of ecosystems. The economic timber model then determines what are the timber types that are optimal to grow and the optimal management options (e.g. rotation time) on the basis of demand. In the global timber market the world demand and the world supply of timber affect local decisions. Therefore, climate change impacts in a far-distant area of the world might affect the timber market locally.

In practice, the evaluation of long-term adaptation in the forestry sector should proceed as follows:

1. A scenario of future weather variability and a socio-economic scenario are prepared;
2. A dynamic forestry-economic model is calibrated to reflect geographic, climatic and other local characteristics of the region under exam; if the project is limited in scope, a global model might be not necessary;
3. The forestry-economic model is used to estimate the impact of climate change on the value of profits without adaptation by not allowing the model to adjust production decisions to the new climate;
4. The forestry-economic model is used to estimate the impact of climate change on the value of profits with adaptation; and
5. The comparison of the scenario with and without adaptation reveals the efficient adaptations and the benefit of adaptation.

Dynamic forestry-economic models can also be used to study adaptation to current climatic conditions following the steps indicated for agro-economic models in Section 2.2.2.

2.4 THE METHODS AVAILABLE: WATER

2.4.1 INTRODUCTION

Water is vital to human life and every ecosystem. It is also a major factor of production and it is consumed by households to perform numerous activities. Agriculture is the major user of water in the world both in terms of withdrawals and consumption. Industry is responsible for the second-largest share of withdrawals. Residential uses represent a smaller quantity of water but extremely critical share. In this Chapter, we examine the opportunities for the water sector to adapt to climate change. Past studies reveal that adaptation can make an enormous difference in the water sector.


Photo Credit: USAID/UNDP

Climate change can have an enormous impact in the water sector partially by changing the demand for water but primarily by changing the supply of water in a watershed. Because of hydrological conditions in each basin, the link between climate and runoff varies from watershed to watershed. Because water is expensive to transfer from one basin to another (it must be pumped over hills), every basin (watershed) is a separate water market. The marginal value of water varies a great deal from one basin to another depending on the density of population and water users (demand) versus runoff (supply). Each watershed is unique from both a hydrologic and an economics perspective. In order to understand how climate change impacts the water sector, one must understand what is happening in each basin.

2.4.2 WATER AND INSTITUTIONS

Within basins, it is relatively easy to transfer water from one user to another. One merely has to decide how much water each user can withdraw as it flows from the headwaters to the sea. In water scarce regions, all the water is allocated (some can be allocated to aquatic ecosystems and thus kept in the waterway). As the demand for water has grown over the last half century, water is now scarce in a large fraction of watersheds. There is no extra or unused water left in these watersheds. In order to give more water to any particular user, it must be taken away from an existing user.

In most systems, water allocations across users are determined by historical assignments of water drawing rights. These assignments were often determined by first come first serve. Whatever user was in the watershed first claimed the available water. Water is generally not allocated efficiently anywhere in the world. For example, water is rarely traded in markets. There are few institutional mechanisms to equilibrate marginal values of water across users to optimize the value of water to society. There consequently are substantial differences in marginal water values across users. In water scarce watersheds, there are often many opportunities to move wager from low valued uses to high valued uses. Such transfers would increase the value of water in the watershed to society at large. For example, residential (urban) users often value marginal water at many times the value that farmers place on that same water. Sometimes poor people must pay private suppliers a far higher price for water than richer people pay public utilities in the same watershed. The water sector lacks a voluntary program where users that value water highly can obtain small amounts of water from users that place a low value on the water in return for compensation.

The existing discrepancies between the marginal values that different users place on water reveal that water is often not efficiently allocated. In most watersheds with scarce water, water could be reallocated from low valued to high valued uses. This would increase the aggregate return that society gets from their current supply of water.

We discuss the efficiency of water allocation in this section because it lies at the core of adaptation to climate change. If climate change alters the supply of water or if it changes the demand for water by some users, one of the critical adaptations is that water should be reallocated. If water can be reallocated from low to high valued uses, it can help a society adapt to changes from climate change more effectively. For example, if warming increases the demand for water for high valued irrigation but not for low valued irrigation, it is important to transfer the water from the low valued irrigator to the high valued irrigator. This could be done voluntarily with a compensation payment from the high valued farmer to the low valued farmer. Such reallocations are inherently fair because they are voluntary. The low valued farmer does not have to make the transfer if the compensation is not adequate. An alternative scheme is that the government simply seize water from low valued users and give the water to high valued users. This leads to the same outcome in terms of where the water goes but all the people who give up water have losses.

The advantage of encouraging more efficient water allocation is that one can dramatically reduce the losses associated with shortages of water supply. If a reduction in supply cuts water from high valued uses, there can be very large welfare losses. If all the lost water is concentrated in low valued uses, the damages are much smaller. There is so much inefficiency in current water allocations that simply making the water supply efficient can compensate for a large share of the losses associate with at least moderate reductions in water supply. Such adaptation practices are critical if climate change makes the reduction permanent. But these adaptations are also quite effective at reducing the loss from temporary supply reductions such as during droughts. One important long-term adaptation for the water sector is to develop institutions that move water from low to high valued uses.

What institutions could be established to allocate water efficiently? One solution is to create a market for water where the government (owner) sells water and each private user buys water. Given the market price, each user would equate their personal marginal value to the price. With the same price for everyone, the system would equate marginal values across users. The market price would equilibrate aggregate demand to supply. This would lead to an efficient allocation of water. Of course, if people currently obtain their water for free or for a nominal price, such a water market would entail a large loss of implicit property rights and may be politically untenable.

A second solution is to establish water rights based on historic use and then simply allow water trading. If high valued users want more water, they could offer to buy it from low valued users. All transactions would be voluntary. Users would trade only if they wanted to. Trading would lead to a market price, a price that equates the marginal value of water across all users, making the allocation efficient. If conditions changed, people would make new trades and establish a new price that equated supply and demand. This voluntary market would be efficient. The difference in these first two approaches is in the initial property rights. Having the government sell water gives the property rights of the water to the government (owner) forcing each user to pay for all of the water that they want. The trading regime gives the property rights to the historic users of water. Users only have to pay if they want more water than they have historically used.
A third solution is that government regulators assign a quantity of water to each user. Users would not pay for water but they would be forced to use only what the government gives them. If the government does a perfect job of allocation, each user would get exactly what they would have wanted in either of the two market approaches above. The marginal value of water would be equated across users and no one would want to trade. The major difference in this government system is that the government is completely in control of the allocation. If the government does not know the marginal value of each user, it cannot allocate the water efficiently. If the government has multiple objectives, they will interfere with efficient water allocation. In general, there is simply too much private information needed for the government to know how to allocate water across all users. Finally, there is a serious problem if special interest groups influence government allocations to get more water.

The arguments above are intended to illustrate that there are multiple institutional solutions to making the water sector more efficient. Some authors believe that institutions will not easily change (Libecap 2011) and so no reform is possible. That may certainly be true in the short run. But in the long run, it is important to develop more efficient water institutions especially in water scarce regions. On a more optimistic note, there is some evidence that more efficient mechanisms are already emerging in water scarce regions (Loomis, Koteen, and Hurd 2003).

WATER MARKETS AS ADAPTATION

Creating institutions that allow for trading of water between different parties (e.g. between farmers and cities) is an important type of adaptation to changes in hydrology brought about by changes in the climate.

2.4.3 TOOLS

2.4.3.1 HYDROLOGIC MODELS OF WATERSHEDS

Most of the studies of climate change impacts on water availability have used hydrologic models of watersheds to understand the link between a climate scenario and the outcome to rivers and streams. In these models, the temperature and precipitation of a climate change scenario is used to study how water runoff in a watershed changes. The change in water runoff then forces a proportional change in use by each final user (Flaschka, Stockton, and Boggess 1987; Gleick; Nijssen et al. 2001). Global Circulation Model scenarios are downscaled to the watershed level to predict changes in temperature and water runoff. Then a hydrological model is used to calculate the changes in hydrologic fluxes. The models take into account typography and the ecosystem characteristics of the landscape (vegetation). For example, dense vegetation leads to increased evapotranspiration and thus reduces runoff.

2.4.3.2 MODELS OF WATER MANAGEMENT

Hydrological models predict the supply (flow) of water in each season, but they do not predict how water is managed. One must add a water management model to know how water is used in a system. Some authors have combined a water management model with a hydrological model (e.g., Lettenmaier and Sheer, 1991; Nash and Gleick, 1991; Frederick, 1993; Miles et al., 2000; Miller et al., 2001; Wilkinson, 2002). These water management models are intended to reflect the current management of the system. Other models examine exogenous (often proportional) reallocations of water given changes in flows (e.g., Cline, 1992; Titus, 1992). These models do not consider either the current management or an efficient allocation of water. A third group of economic models attempt to calculate the efficient allocation of water.

The economic models, known as Watershed Allocation Impact Models (Water-AIM), allocate water to their highest valued use. Sectors (users) that have higher marginal values for water get a larger share of water than they do now. These models link planning authorities, managers and users in a partial equilibrium model in which water is traded spatially and over time in the same watershed, taking into account the specific features of each river basin (Hurd et al. 2004). Water-AIMs are used for many purposes in the USA including climate change impact estimates and adaptation (Howitt, 1984; Booker and Young, 1991; Hurd et al. 1999; Hurd and Harrod 2001).

HYDROLOGICAL MODELS AND THE OPTIMAL RESPONSE

Hydrologic models allow us to determine the quantity and timing of discharge in a given watershed – very useful when we think of temperature and precipitation changes as the climate changes. Coupling a hydrologic model to an economic model allows us to not only predict flow quantity and timing but also the response of agents that use that water. Thus, with changes in flow patterns, we will look to use water for maximum social value.

In addition to modelling water withdrawal, Water-AIMs can also simulate the demand for in stream water uses such as recreation, cultural and ecosystem values. These in stream values keep some water from being withdrawn at all. The Water-AIM models effectively simulate a water market where users pay an implicit price for water with no externalities or impediments. The models lead to the same water allocation results that would occur if there was water trading or if government agencies regulated water to maximize the value to society.

Of course, water withdrawals can be complicated. There are externalities to water withdrawals as users rarely consume all their withdrawals. Some of the withdrawal can benefit nearby neighbours creating a positive externality. This is not always taken into account by the models, or by water institutions. Nonetheless, Water-AIM models can be used to study adaptation measures because they deliver the set of efficient investments in river-basin management, the set of efficient management practices and the optimal allocation of water across uses and sectors.

2.4.3.3 MODELLING WATER ALLOCATION WITH CLIMATE CHANGE

How do Water-AIMs allocate water across users? Currently, most water withdrawals are allocated to farmers. The marginal value of water to farmers is often quite low compared to other users. In contrast, the value of water for industrial and residential water uses is often relatively high. If the fraction of water used by each water user remains fixed as it is today and climate change causes a drop in runoff, there would be very high damages from losses of water to urban and industrial users. By reallocating water from low valued uses (farming) to high valued uses (urban), however, it is possible to dramatically reduce the damages from runoff reductions.

Studies of the Colorado River predict likely reductions in supply with global warming. The damage from reduced supplies of water can be very high if they entail large reductions in water to Los Angeles. The economic model reveals that damage can be substantially reduced by reallocating current water allocations away from low valued and towards high valued uses. Models of the Colorado suggest one can increase the aggregate value of water by reallocating water from upstream agriculture to the downstream urban uses (Hurd et al 1999). This allows the water to pass through high valued hydroelectric dams and it preserves water used by valuable downriver urban uses (Hurd et al. 1999). The damages from supply reductions fall dramatically. Studies of other river systems produce similar results suggesting that moving water from low to high valued uses will be an effective adaptation if runoff falls (Hurd et al. 1999; Hurd and Harrod 2001).

A similar result occurs in California where a complex array of canals and rivers allow large shifts in water from one place to another as runoff falls (Lund et al. 2006). The most efficient response to reductions in supply in this system is to reduce water to low valued agriculture (irrigated land growing crops for animals). This would in turn preserve high valued agriculture such as vegetables, vineyards, and orchards as well as urban uses. By reducing low-valued agriculture in the Central Valley, the state could absorb a 25 percent reduction in runoff with only a 3 percent reduction in agricultural gross domestic product (GDP) and virtually no losses for urban and industrial uses (Howitt and Pienaar 2006). This is not just an abstract modelling exercise. California recently survived a large drought by paying low valued farmers to stop withdrawing water during the drought. The state survived the drought with minimal economic losses.

In addition to identifying the "best" adaptation, another value of these models is that they quantify what society and each member of society loses with every adaptation choice. That is, they quantify the losses associated with every adaptation choice so that a decision maker can see both the overall consequences of each decision to society as well as the distributional consequences across different users.

2.4.4 WATER AND AGRICULTURE

The water and agriculture sectors are closely linked. A large fraction of consumed water is used by agriculture. As temperatures rise with global warming, irrigation is one effective tool to compensate for the faster transpiration of plants. Several studies have shown that irrigation increases the benefit of warmer climates using cross-sectional evidence in the United States (US) (Mendelsohn and Dinar 2003; Schlenker, Hanemann, and Fisher 2005) and in developing countries (Kurukulasuriya et al. 2006; Kala, Kurukulasuriya and Mendelsohn 2012; Fleischer and Kurukulasuriya 2010).

Irrigation is clearly one of the most important adaptations that farmers can take. Warming would increase the marginal value of irrigation and induce farmers to pay water more or invest in irrigation projects. Reduced natural rainfall will also increase the marginal value of irrigation, while increased rainfall would lower the value of irrigation. Changes in rainfall will instead have a reduced impact in areas in which irrigation is already intensive. If water becomes scarce, farmers will want to invest in more expensive, efficient, irrigation methods.

Several studies used cross-section evidence to estimate the cost and the water requirements of alternative irrigation methods (Mendelsohn and Dinar 2003; Fleischer, Mendelsohn, and Dinar 2011).

Sprinkler and drip systems are more expensive but more water efficient than gravity irrigation systems. As water become more scarce, farmers will want to switch from gravity to sprinkler and finally to drip systems (Mendelsohn and Dinar 2003). But more advanced systems are also more expensive so they will likely be adopted only in more fertile locations.

IRRIGATION AS A RESPONSE TO CLIMATE CHANGE

Irrigation technologies such as sprinklers and drip systems are an adaptation by farmers to changing climate. You can check for the choice of investment in irrigation technology by statistical means, which will allow you to gauge what kind of climate results in investment in a given irrigation technology.

Cross-section methods used to study adaptation in the agricultural sector can be applied to water management practices by farmers. Data at the farm level is the most appropriate. This data can reveal how farmers have adopted specific irrigation and water saving technologies to the climate and soil conditions they face.

METHOD RECAP
WATERSHED ALLOCATION IMPACT MODELS

What You Will Need

1. Data:
   a. Data to calibrate a hydrologic model. Typically these are temporally fine data such as river runoff, precipitation, evapotranspiration and temperature. You will also require environmental data such as soil type, topography (e.g. slope and altitude).
   b. Economic data to calibrate an economic optimization model.
   c. Climate predictions for the region(s) you are studying (available from the IPCC).
2. Hydrologic model (see the United States Geological Survey website for a selection of such models). Select one based on the kind of data you have available to calibrate the model.
3. Economic optimization model. You will need someone with a good knowledge of programming and economics to set up an optimization model for you. Also, this model needs to be able to "talk" to the hydrologic model.

What You Need to Do

1. Calibrate the hydrologic model based on its requirements. Again, make sure you have adequate data for the hydrologic model you have picked.
2. Setup the economic optimization model. See Hurd et al (1999) for an example of how to do this.
3. Use your climate predictions to see how moisture flow predictions change in the hydrologic model.
4. Use the economic optimization model to determine what the best allocations of water are given the changed climate.

The Results

Your hydrologic model coupled with the economic optimization model should tell you how water allocations would change among water users when climate changes.

2.4.5 WATER AND ENERGY

Water is an important input for many industrial processes, electricity generation in particular. Hydroelectric power plants rely on water for power generation and will be greatly affected by changes in flow. Hydroelectric power plants will have to adapt in many ways to a changing climate. Madani and Lund (2010) have studied how climate change might affect optimal operations of hydro power plants in California using the Energy-based, Hydropower Optimization Model (EBHOM). The model requires data on monthly runoff, storage capacity and generation capacity. Data on runoff was generated by downscaling GCM scenarios at the basin level, at different elevations. Most importantly, the model maximizes net revenues from electricity sales rather than electricity generation. One way to increase the value of the electricity from dams is to use them to for peak demand supply. During daily peak demand, the price of electricity is higher. Electricity generated in this period thus leads to higher revenue. Generating more electricity during peak periods is one adaptation that increases revenue. Storage capacity can limit the increase of net revenues in a wet scenario. One consequently might want larger dams if rainfall increases over time. The price of electricity can change in response to changes in climate. Failing to account for the market response would deliver a biased estimate of the economic impacts of climate change.

The energy sector also relies on water to cool thermoelectric power plants, which are built for this reason close to rivers, lakes or the coastline. This is a sector in which water, energy and coastal management are strictly intertwined. Power plants withdraw a large amount of water but only a fraction evaporates and is lost in the cooling process. The warmed water is then released back in the river, lake or sea. Thermoelectric power plants might not be a large net consumer of water but such plants can withdraw very large quantities of water. A reduction of the water flow below a minimum threshold forces power plants to operate at lower capacity.

Many power plants in operation have long residual lifetimes. If climate change reduces the amount of water available for cooling, power plants may want to adapt to these new conditions. One choice available to power plants is to build water-cooling towers. These towers consume more water by evaporated water into the atmosphere but they require smaller water withdrawals.

Short-term solutions to temporary water shortages should also be developed. Droughts may make some plants have to shut down. Power grids need to develop broader supply bases so they can turn to alternative sources (far from the drought) to substitute for the lost power. By sharing supply across a wider geographic base, the system may be able to be more resilient at relatively low cost. Such system wide responses are important adaptations.

METHODOLOGICAL NOTE

You can conduct the analysis of water and energy in a similar manner to that for water and agriculture by including dams and other hydropower production features in your hydrologic model and economic optimization model. Water that flows through the dams is valuable. So dams do not consume any water but they do cause the value of upstream water to increase, and thus discouraging upstream water consumption.

2.5 THE METHODS AVAILABLE: ENERGY

2.5.1 INTRODUCTION

Climate change impact on the energy sector will be two-fold. First, climate change will alter the demand of energy by inducing individuals and firms to warm less and cool more buildings. The literature shows that climate can have a large impact on energy demand. Second, climate change will affect the supply of energy by affecting power generation plants, transmission lines and power distribution centres. Hydroelectric power plants are directly affected by changing water flows. Thermoelectric and nuclear power plants can be affected by limits on cooling capacity. High temperatures can reduce the ability of transmission lines to carry large quantities of electricity. Power distribution systems may face more intense peak demands to meet mid-day cooling needs. This section illustrates methods used to estimate optimal adaptation strategies in the energy sector.[8]

Photo Credit: USAID/UNDP

2.5.2 ENERGY DEMAND

Climate change will affect air temperatures and comfort indexes making life potentially more uncomfortable in tropical and temperate areas of the world. Estimating how energy demand will change as a consequence of climate change is useful for two reasons. First, it shows possible adaptations that households and individuals will take in the face of global warming. Second, by understanding how demand might change (quantity, quality, geographical distribution and temporal distribution), it will be possible to adapt energy supply accordingly.

By studying how people have adapted their energy related choices to climate and weather, it is possible to extrapolate how climate change might lead to future adaptation responses. A large body of research has used econometric methods to establish a relationship between climate and energy demand in buildings. Results show that people and firms react to warming by cooling more in summer and heating less in winter (Mideksa and Kallbekken 2010). This literature estimates how much cooling and warming are likely to change per degree Celsius of warming. In a temperate climate, studies show that the additional energy used for cooling would roughly offset the lower amount of energy for warming (Rosenthal and Gruenspecht 1995). However, cooling is more expensive than warming, so although the total energy use (BTU's)

[8] A comprehensive overview of how climate change might affect the energy sector was commissioned by the World Bank (Ebinger, Vergara, and Leino 2011).

might not change, the energy expenditure to stay comfortable will increase (Morrison and Mendelsohn 1998). Although the additional cooling is often treated as damage, it is really an adaptation that keeps people more comfortable and can sometimes protect their health. For developing countries in the tropics, which have relatively small winter heating costs, the increased cooling expenditures are potentially quite large sources of net damage. Cooling damages may be especially problematic as developing countries become wealthier and can afford more cooling capacity (Depaula and Mendelsohn 2010).

Econometric studies have shown that in addition to shifting towards cooling, people will also change fuels (Mansur, Mendelsohn, and Morrison 2008). Warming will cause an increase in electricity demand and a reduction in other heating sources (primarily oil and natural gas). With the desire for more cooling, there will also be an increase in cooling equipment. Households will move from fans to portable air-conditioners to central air conditioning. This increase in capital will in turn lead to more cooling and more energy use.

**SPACE COOLING:
AN EXPENSIVE ADAPTATION**

Locations that are already warm will look to cool more with each degree Celsius increase in temperature. Cooling tends to be more expensive than heating and has expensive capital requirement (such as air conditioning systems). More cooling also means a shift in the fuel types used (more electricity and less oil and gas).

Econometric, cross-sectional methods, based on estimating energy demand at different climates, can thus provide estimates of how energy demand will vary in different seasons and thus contribute to designing adaptation in energy systems. The same methods also provide useful information on the adaptations that private individuals and firms would autonomously implement when facing higher air temperatures. This information can be used to estimate the cost of adaptation of households and firms. It is important to note that the adaptations that the individuals select are the most economically efficient, given their tastes and the choices available.

Several energy studies have been carried out for the United States, Europe and other industrial economies (Mansur, Mendelsohn, and Morrison 2008). Few studies have examined developing countries (Depaula and Mendelsohn 2010). More studies in developing countries are needed to understand how people have adapted to different climatic conditions using local technologies other than air conditioning. For example, building designs such as high ceilings or open walls might reduce the demand for air conditioning in some settings. In contrast, metropolitan areas in developing countries might react more similarly to developed countries by investing in cooling. Each country should investigate its own energy system to understand how both demand and supply might be affected by climate change.

In order to carry out a cross-section study of energy demand and climate it is necessary to have data on energy consumption, socio-economic variables, housing characteristics and climate for a large sample of families. National census data often contains information on all these variables and can be the starting point for a cross-section study.

Engineering methods can estimate the amount of energy needed to keep a room at a particular temperature given outside temperatures. Such studies have distinct advantages. They can be very precise and can carefully control for extraneous factors. Engineering models can consider a large set of technologies including technologies that are not yet adopted (new). However, engineering studies also have drawbacks. Sometimes engineering models fail to capture the heterogeneity of conditions facing consumers. Engineering studies often fail to recognize consumer preferences and behaviour. They can recommend a single solution for everyone, such as an air conditioner, when in fact the range of conditions and circumstances may suggest multiple solutions are preferable. Finally, many technological choices have multiple dimensions. For example, different light bulbs may give off different types of light or may take time to brighten. How much energy each light bulb uses may be only one important characteristic. If studies do not capture all the important dimensions of a choice, they may suggest unpopular choices. Finally, engineering studies often fail to anticipate changes in consumer behaviour that technologies might induce. Adopting a more efficient light bulb, for instance, may encourage some consumers to keep it on longer. Both engineering and econometric methods are best used together with energy-economy models to predict how future climate change is going to affect future energy demand and composition.

METHODOLOGICAL NOTE

As with other sectors, more than one method can be used to study adaptation in the energy sector –In this review, we compare economic and engineering studies. Economic studies tend to rely on econometric models of household and firm behaviour in different climates. For example, one can use a panel model of weather and electricity use or a cross sectional comparison of energy demand and climate. Engineering studies tend to rely on controlled experiments that relate for example interior temperature with exterior temperature. They might explore the cooling energy required to maintain a certain indoor temperature with exterior warming.

An economy-energy model should forecast future baseline energy demand. The model should account for changes in demand that are not related to climate, for example changes in household square footage or changes in cooling technology. Energy studies in developing countries must account for future changes of income, as these will invariably increase energy demand. The change in level and composition of energy demand due to economic development will likely be much bigger than any change induced by global warming. There is already a very large increase in the demand for cooling in emerging economies associated with their rapid economic development. This increase in demand should not be attributed to climate change. These changes are part of a dynamic baseline that would occur even without climate change. The question for policy makers is how will climate change alter this already growing baseline demand for energy.

METHOD RECAP
EXPLORING ENERGY DEMAND

What You Will Need

1. Engineering Data:
    a. Experimental data concerning the energy needed to cool or heat buildings as exterior temperatures change.
2. Economic Data
    a. Energy use or expenditures by firms or households in different climate zones
    b. Energy use or expenditures over time in different weather outcomes

What You Need to Do

1. Extrapolate the engineering results to the population of housing.
2. Estimate the energy economic model from the sample of data.
3. With both sets of results, explore how energy demand varies with climate change.

2.5.3 ENERGY SUPPLY

Energy supply will have to adapt to the changes in aggregate demand discussed above. The energy system will also have to adapt to changes in the ability of power plants to generate electricity and the ability of the transmission system to distribute it. Higher air temperatures will reduce the efficiency of thermoelectric power plants. Lower flows will pose challenges to hydroelectric power plants. Water is also an extremely important input in thermoelectric and nuclear power generation: it covers 40 percent of surface water withdrawals in the USA and 43 percent in Europe (Vliet et al. 2012). Extreme events – such as cyclones and tornadoes – might also affect energy generation from wind and solar power generation to oil refineries and drilling platforms. Changes in cloud coverage might alter the efficiency of concentrated solar power plants.

Climate also affects transmission systems. Higher temperature reduces the ability of transmission lines to carry large volumes of electricity. Higher temperatures may affect pipelines. Storms create havoc with transmissions systems. Adapting energy supply to a changing climate is possible. The intrinsic efficiency of combustion processes does decline with higher temperatures as a result of the second law of thermodynamic. But improvements in power plants efficiency might offset the negative impact of warming. More advanced water-cooling technologies might compensate for lower river runoffs for nuclear and thermoelectric power plants. Recirculating cooling systems require less water than once-through cooling systems and dry cooling towers might replace water altogether in cooling processes.

Vliet et al. (2012) use a hydrological and water temperature-modelling framework to produce a multi-model ensemble of daily river flow and water temperature projections for Europe and the US over the twenty-first century. The hydrological model is able to convert scenarios generated by GCM models to changes in water runoff and water temperature in rivers. Using three GCMs, and the B1 and A2 SRES scenarios, the authors find that higher water temperature and decreased runoff has a negative impact on electricity generation potential for 76 percent of the power plants with once through or combination cooling systems and for 41 percent of the power plants with recirculation systems, during summer in the 2040s. The average usable capacity of power plants with once through or combination cooling systems decreases by 12–16 percent (US) and 13–19 percent (Europe) in the 2040s. The occurrence of periods with large reductions in usable capacity will increase in the 2040s, as shown by the return period plots for the power plants New Madrid (US) and Civaux (France; Figure. 3b). Replacement of once through by recirculation systems is a possible adaptation measure because it reduces freshwater withdrawal. However, water consumption increases because water is used more intensively and evaporates more. Dry cooling systems or non-freshwater sources for cooling could be used as alternative to water-based systems, but are more costly. Most interestingly, the authors find that switching from nuclear to coal power plants to new gas-fired power plants with higher efficiencies could reduce water demand significantly. In order to study the optimal adaptation measures it is therefore necessary to have a wide economy-energy model in which the optimal mix of power plants depends also on water availability. Furthermore, the estimated impacts should cover all seasons and not only summers.

Climate change may also affect wind power generation by changing the geographic distribution and/or the inter- and intra-annual variability of wind. Possible adaptations include: optimal placement of wind farms and adaptations of wind mills design to new prevailing wind speed and frequency. In order to study adaptation is therefore necessary to have a model, which predicts future wind patterns. Researchers have traditionally used downscaled scenarios from GCM to predict local wind patterns. This is a complex exercise, which is subject to a high degree of uncertainty (Pryor and Barthelmie 2010).

METHODOLOGICAL NOTE

Methodologically, estimating energy supply impacts is difficult, as it requires a large pool of experts in different domains to collaborate. However the core actions required can be stated as follows:

1. Determine the energy coming from each source of energy supply;
2. Determine which sources are sensitive to temperature and water flows;
3. Determine how each energy source will be affected by each climate scenario;
4. Determine the cost of providing energy from substitute energy sources.

Climate change will affect energy supply in a large variety of ways. As a general rule, in order to study optimal adaptation methods researchers need to employ models of the climate system, models of the earth system, engineering models, energy system and economic models together. Possibly, some models have two or more parts integrated in the same optimization framework. For example, energy-economy models with high engineering detail are already available. In this case the researcher must couple the energy-economy model to a climate change scenario to study the impact of future climate change on the future energy system. The model should then be able to find the economically efficient adaptation measure. Models that determine energy demand and supply simultaneously would offer useful insights because they would link impacts on demand and supply, jointly determining optimal adaptation in supply and demand. Downscaling climate change scenarios at the geographical level at which energy is consumed and transformed is a difficult task surrounded by large uncertainties. Studying optimal adaptation measures in the energy thus requires a pool of experts, which can master a set of complex tools and methods.

2.5.4 HEAT WAVES AND ENERGY

Heat waves affect the energy sector by reducing the efficiency of thermoelectric power plants, changing water available for cooling, limiting the amount of electricity that can be carried by transmission lines, and by increasing energy demand. Heat waves are also a health threat. There are many health studies that have verified increases in daily mortality associated with temporary heat waves. One important adaptation to heat waves is to invest in cooling, especially air conditioning. However, even fans can help most people survive a heat wave.. Many community adaptations involve providing public spaces that are cooled during heat waves. For example, there are community programs in the United States that bus elderly residents to nearby air-conditioned shopping malls. Cooling is consequently an adaptation to heat waves. The cost of the adaptation is the extra capital and operating costs required to cool a building. The benefit is the comfort and reduced health effects to the consumer.

2.5.5 COOLING AND MITIGATION

As much as cooling is an adaptation to warming, it clearly causes an increase in energy demand which in many cases will lead to increased emissions of greenhouse gases. This is a clear example where adaptation is in direct conflict with mitigation.

One option is not to consider adaptations that lead to increased emissions of greenhouse gases. However, in some circumstances, such as the cooling case, this is an important adaptation and would be costly to abandon. An alternative option is to properly price the increased emissions when considering the adaptation. In this case that implies valuing each ton of emission at the social cost of carbon, the present value of damage caused by that ton. The literature is full of estimates of the social cost of carbon including the Second IPCC report (Pearce et al. 1996). Adding the social cost of carbon to the electricity price makes it more expensive

(Muller et al. 2010). However, it takes into account the subsequent damage to the environment. If the benefit of the adaptation still exceeds the higher cost, then it is worthwhile undertaking. If the higher price makes the adaptation too costly, then it should be avoided. There is consequently a systematic way one can evaluate adaptations that inadvertently result in greenhouse gas emissions.

2.6 CROSS-CUTTING ITEMS

2.6.1 COASTAL SEA-LEVEL RISE

Climate change will induce sea-level rise by increasing water temperature and thus its volume (thermal expansion) and by melting land-based ice. Sea-level will rise gradually and will continue to rise long-after the temperature has stabilized due to the large inertia of the oceans and of the large ice sheets in Antarctica and Greenland. Sea-level rise affects all coastal lands in the world, although it will be greater in some regions due to local conditions. The IPCC estimates that sea level will rise from 0.4 to 1.0 m by 2100.

The direct effect of sea level rise is that it will inundate coasts. This can result in very high damages because coasts are densely populated, with a large fraction of productive assets, including ports, industries, transport and energy infrastructures and residential properties. Tourism and agriculture will also be affected by sea-level rise. Indirect impacts of sea-level rise include coastal erosion and salt-water intrusion of fresh-water aquifers. Natural ecosystems can be affected as salt water enters lagoons and river deltas. Sea-level rise will magnify the potential threat posed by storm surges and by floods in estuary regions. For this reason the economic impact of sea-level rise was one of the first sectors to be studied in climate change research (Yohe 1990; Cline 1992; R.J. Nicholls et al. 1995).

Photo Credit: USAID/UNDP

Some studies of sea level rise overestimate coastal damage. These analysts calculate the property along the shoreline from the original to the new shoreline and sum the value of the lost property and capital at current market values. This overestimates the damage because the shoreline is not lost, it is just moved. Property that was originally inland will sharply increases in value when it becomes shoreline. Strictly summing the lost shoreline consequently overestimates the value of the loss. The loss is the lost physical structures along the coast and land in the interior. It is the interior, which shrinks, not the coastline. So the lost property must be valued as though it were in the interior, not on the shore (Yohe 1990; Neumann et al. 1999).

But the most important thing to understand is that society can adapt to sea level rise by building sea walls, by adopting integrated coastal zone management, by nourishing beaches, among many other possibilities. The question in each case is what is the less expensive option, the lost property from inundation or the construction of hard protections. Sea walls are expensive and their cost rises with the square of their height. However, the land that they can protect from inundation can be even more valuable than the cost of the sea wall itself. In general, developed coastal areas (urban areas) are worth far more than the cost of sea walls. It is cheaper to build a sea wall around urban areas than to allow inundation (Yohe 1990; Neumann et al 1999; Neumann and Livesay 2001; Ng and Mendelsohn 2005). Virtually all urban areas should be protected from sea level rise over the next century. Of course, that will not necessarily apply to undeveloped land.

What agent is best able to build sea walls? One might expect that private property owners would be perfectly eager to build sea walls in front of their own structures. In practice, however, the chance of flooding often depends not only on what a single owner does but also upon neighbour's actions. Flooding generally depends on the lowest portion of a sea wall along a section of coast not just what is at the front of each house. There is a clear role for government in sea wall construction to assure that walls are built uniformly along each strip of coast to protect everyone there. Sea wall construction along a private coast may be a perfect opportunity for public –private cooperation. The primary beneficiaries of the sea wall are the private homes behind it. Yet there is a coordination role needed from government. The government could specify the minimum heights of walls. The government could also possibly subsidize part of the cost to cover the value of protecting public resources. Private investment could then be encouraged to pay for the construction itself.

Sea level rise adaptation for less developed land is less clear. For example, whether to build sea walls to protect farmland would depend on the acreage protected and the value of the farmland. Society might want to protect beaches and other natural areas as well (wetlands and mangroves) but the construction of sea walls to protect natural lands has to be done thoughtfully. For example, a large wall between a sandy beach and the sea may sharply reduce the attractiveness of the beach for recreation. Sea walls for beaches may have to be built under the sea. This would keep the sand in place but not create a barrier to swimmers. Although technically possible, this is more expensive and probably only justified for the very highest valued beaches (Ng and Mendelsohn 2006). Sea walls between the sea and natural areas such as mangroves and marshes can be more destructive than beneficial if they cut off the natural area from the ocean they depend upon.

Other long-term adaptations include locating valuable facilities further from the shore. For example, power plants could be located further from the shore provided piping is built to carry cooling water back and forth to the plant. New housing developments could be encouraged to locate at higher elevations. It might be sufficient simply to make clear how short the lifetime of such investments might be if built too close to the shoreline.

Existing structures that will be inundated can be depreciated. The advance of the shoreline is often slow enough that owners have decades to anticipate when they will lose a structure. As lifetimes shorten, owners can simply reduce maintenance expenditures and let the buildings deteriorate. This slightly reduces the overall damage of inundation (Yohe 1990).

There are many real world examples of sea walls being used to hold back the sea. The Netherlands has reclaimed large portions of land from the sea with massive sea-walls. Cities like Singapore have expanded by building on what was water. Tokyo, Bangkok and Shanghai have subsided by 5 m, 3 m and 2 m respectively during the 20th century and now rely on sea walls and water management infrastructure (Nicholls et al. 2008).

Nicholls et al. (2011) study alternative adaptation options to protect global coastal land. The study starts by assuming a sea-level rise of 0.5 m-2 m in 2100, consistent with a high warming scenario. The global sea-level rise scenario is downscaled using a model that assesses glacial melting and natural subsidence. The study then uses the Dynamic and Interactive Vulnerability Assessment (DIVA), an integrated model of coastal systems that assesses biophysical and socioeconomic impacts driven by climate change and socioeconomic development (Hinkel and Klein 2009; http://diva-model.net). The model uses exogenous drivers for coastal population, economic development and land allocation among residential, industrial and agricultural uses. Within this framework alternative mitigation options are assessed on the basis of the costs and benefits. Nicholls et al. (2008) have ranked major global port cities on the basis of exposure to sea-level rise with and without adaptation. Their study is also based on the DIVA model, on GIS models and on exogenous assumptions on population growth and distribution, economic growth and economic value of assets at risk. The adaptation possibilities evaluated with the DIVA model are: (a) upgraded protection; (b) managing subsidence (in susceptible cities); (c) land use planning to reduce vulnerability, including focusing new development away from the floodplain, and preserving space for future infrastructure development; (d) selective relocation away from existing city areas; and (e) flood warning and evacuation.

2.6.3 HEALTH

Climate change will affect health in three ways (for a review see NIEH 2010). First, higher temperatures will have a direct impact on health by reducing morbidity and mortality associated with cold weather and by increasing morbidity and mortality associated with heat waves. Second, climate change will indirectly affect morbidity and mortality by altering aero-allergen production and secondary pollution formation. Third, climate will affect vector-borne and water-borne disease. For example, warmer and more humid climates will expand the habitat of the mosquito that transmits malaria, thus indirectly affecting morbidity and mortality in areas where malaria is now not present. Of course, climate may also affect health through agriculture but this is covered in the agricultural analysis.

In this section, we examine methods used to study optimal adaptation measures to reduce the morbidity and mortality, directly or indirectly associated with long-term warming. Section 2.6.5 address other life threatening categories of impacts – e.g. cyclones and droughts. This section also introduces methods to estimate the economic losses associated with morbidity and mortality. Those methods can be applied to study the economic benefit of alternative adaptation measures to both extreme events and long-term climate warming.

2.6.3.1 HEAT WAVES AND COLD EVENTS

Many epidemiological studies have tied heat waves to increased mortality and hospital admissions (WHO 2003). The 2003 heat wave in Europe caused 30,000 deaths (Beniston 2004). People that were isolated or living at the top floor of apartment building blocks had higher mortality rates than people with good social ties and living in houses with high insulation (Vandentorren et al., 2006). In many instances, poorly organized local governments were not able to locate elderly living alone leading to higher deaths. Using data from both the 2003 and 2006 heat waves in Europe, the excess mortality during the 2006 heat wave in Europe was much lower than one would have predicted given the earlier heat wave (Fouillet et al. 2008). Adaptive measures prevented as many as 4,400 deaths. Further, many epidemiological studies find that people in the northern US are far more sensitive to heat waves than people in the southern US. This implies that people in the warmer south have adapted to warmer temperatures. In contrast to all this evidence of adaptation and many epidemiological studies, one study finds that people in the South of the US are just as sensitive to high temperatures as people in the North (Deschenes and Greenstone 2011) implying no adaptation at all.

Several economic studies have specifically tried to determine what adaptations are effective against heat waves. Air conditioning, house design, indoor/outdoor time allocation, early warning systems, fans, and social centres with air conditioning all are effective. The fact that people use more electricity (presumably for cooling) during heat waves (Auffhammer and Aroonruengsawat 2011) confirms some of the choices above. This also ties into the discussion of energy and warming discussed in the energy section.

In temperate countries, empirical evidence shows that mortality has a well-defined seasonal pattern. Mortality usually peaks in winter and is lowest in summer (WHO 2003). The seasonal results may suggest that cold average temperatures are harmful and warm average temperatures are beneficial to health. But it is possible that there are other factors causing high winter deaths. For example, there is also less sunlight in the winter.

METHODOLOGICAL NOTE

One strategy for measuring the link between climate and health is to conduct cross-sectional studies of health outcomes across climate zones. This approach has provided a great deal of insight into the consequences of chronic exposures to pollution and so is likely to work for climate as well. However, care must be taken to include control variables that may be spatially correlated with climate that can have their own effect on health.

An alternative approach is to rely on panel data that explores the effect of weather on health. Of course, weather is not the same thing as climate but it is related. If panel data can reveal that weather causes health effects, it provides further evidence that climate is likely relevant as well.

The literature has found that people living in cooler locations are more vulnerable to heat waves than people in warmer locations. That is, most heat wave deaths occur in cool countries (EMDAT 2012). The effect of heat waves on health is not at all the same as the effect of warmer climates on health. The temperature with the fewest daily deaths in Sweden is equal to 19 °C but it is 29 °C in Singapore.[9] However, people in Sweden and Singapore both have an 81-year life expectancy at birth.[10] The fact that mortality rates are quite similar for people in very different climates may suggest that the average temperature is not important. Alternatively, it may suggest that people are very good at adapting to average temperature. It may just be that daily deviations from the average are harder to adapt to.

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[9] Data on London from Hajat et al. (2002), on Taiwan from Martens (1998), both cited in Patz et al. (2005).
[10] United Nations World Population Prospects: 2006 revision – Table A.17 for 2005-2010.

2.6.3.2 AIR POLLUTION

Climate – temperature, precipitation, clouds, atmospheric water vapour, wind speed, and wind direction – affects the distribution, concentration and formation of ground-level ozone, particulate matter, sulphur dioxide, nitrogen dioxide, and carbon monoxide; all pollutants with negative health impacts. The concentration of pollutants is higher in the presence of anticyclonic or high pressure systems, which are cause of low winds and high temperatures (Schichtel and Husar 2001; Rao et al. 2003). Possible effects of increased exposure to these pollutants cause exacerbated chronic heart and lung disease, accelerated lung aging, increased lung cancer risk and increased risk of premature death (Bernard et al. 2001). Climate has also a direct influence on the distribution and formation of aeroallergens (e.g. pollens), which are responsible for allergic diseases, asthma and allergic rhinitis (Bernard et al. 2001).

The concentration of ground-level ozone is largely affected by temperatures and winds and causes hospitalization for pneumonia, chronic obstructive pulmonary disease, asthma, allergic rhinitis and other respiratory diseases (Confalonieri et al. 2007). Bell et al. (2007) studied how climate change could alter ground-level ozone concentrations and mortality in fifty cities in the US in 2050 with respect to 1990. The authors first estimate the relationship between current climate and current ozone concentrations. They then use GCM scenarios to predict future climate in 2050 and see how the concentration of ozone might change, keeping all the emissions of all particulates and substances that lead to the formation of ozone fixed. The impact of higher ozone concentrations on human health is assessed using estimated concentration-response (or dose-response) functions from the literature. Keeping all other factors constant, the authors show that an average summer in 2050 would have higher ozone levels. This translates into a 0.11 percent to 0.27 percent increase in daily total mortality. The authors do not take into account adaptation nor do they value this increased morbidity and mortality in monetary terms.

There are two effective ways to reduce pollution-related health impacts. One is to avoid exposure. Early warning systems predict when air quality is poor. By avoiding strenuous outdoor activity during such days, people can lower their exposure to ground level ozone. The second measure society can take is to lower emissions of the primary pollutants (oxides as nitrogen - NOx and volatile organic compounds - VOCs) that lead to ozone formation. By reducing the concentration of the precursors to ozone, one can control the concentration levels.

There is a large literature that estimates the costs of early warning systems and the cost of pollution emission reductions. By combining estimates of the cost of health impacts and estimates of adaptation measures it is possible to determine the optimal amount of resources to direct to adaptation and to select the adaptation measures that yield the highest benefit.

2.6.3.3 VECTOR BORNE DISEASES

Climate has an indirect influence on health by determining the distribution of vectors for infectious diseases. Table 1 presents a list of vector-borne diseases that are considered to be sensitive to climate. Climate affects the presence of vectors, their number, their behaviour and their ability to transmit the disease. Changes in temperatures have a great impact on vectors because they have not developed mechanisms to regulate their internal temperature (WHO, 2003).

Table1: Vector-borne diseases sensitive to climate (Table 8.1 of WHO, 2003)

VECTOR	DISEASES
Mosquitos	Malaria, filariasis, dengue fever, yellow fever, West Nile fever
Sand-flies	Leishmaniasis
Triatomines	Chaga's disease
Ixodes ticks	Lyme disease, tick-borne encephalitis
Tsetse flies	African trypanosomiasis
Blackflies	Onchocerciasis

Epidemiologists use the term "vectorial capacity" to define the ability of a vector population to transmit disease. The vectorial capacity of the mosquito is a function of the daily biting rate of a female mosquito, the efficiency with which an infective mosquito infects a human, the chance that an uninfected mosquito acquires infection from biting an infectious person or animal, the probability of daily survival of the mosquito, and the incubation period of the parasite inside the mosquito. The biting rate, the mosquito mortality rate, and the incubation period are the factors the most influence the vectorial capacity of the mosquito and are all affected by climate (WHO, 2003). A combination of higher temperature and higher moisture will increase the habitat of vectors, possibly pushing them into areas where they are not present today. A reduction of rainfall and moisture in general has the potential to reduce the habitat of the vectors.

(Mendelsohn 2000) identifies both private and public adaptations to reduce the risk from vector-borne diseases. Private adaptations by households consist of many measures to avoid insect bites. They include the use of repellents and mosquito nets. They also involve reducing outdoor exposure (many females mosquitoes bite in the evening for example). There are also a host of adaptations for the public sector to take. The public sector can spray insecticides to reduce the population of the vector. The public sector can reduce the habitat of the vectors. International agencies might sponsor new vaccines or treatments for infected people. The public sector can disseminate information to help individuals make better choices. In order to plan for adaptations, it is first necessary to evaluate (a) how climate change will affect disease rates where they are already present, (b) how climate change will spread the disease to new places in the future (c) the vulnerability of the population at risk, (d) and the economic impact of the disease.

WHO (2003) identifies two main categories of models used to study the relationship between climate and vectors. Biological models of vector-borne disease transmission are based on laboratory data, which is then applied to all areas. A second class of models uses statistical methods to estimate the probability of observing the disease with a given climate, using geographic, biologic and socio-economic control variables. Models that rely on laboratory-type evidence must be careful extrapolating from the laboratory to the field. Models that estimate a reduced-form statistical relationship between climate and crops/diseases might be plagued by omitted variables. It is always possible that some hidden variable explains the disease and the study may have incorrectly attributed the disease to climate. Ideally, both laboratory studies and statistical studies confirm similar results.

As discussed in other sectors, there is a clear trade-off between the complexity of the model and the ability to replicate the study in different areas. Disease models that require extremely detailed local climate measures may be frustrated with what climate models are capable of forecasting both in terms of temporal detail and geographic detail. A large number of studies have estimated how climate change will affect the distribution of major infectious diseases. Martens et al. (1999) and Rogers and Randolph (2000) have developed models for malaria diffusion at global regional and local level based on statistical methods. Craig, Snow, and le Sueur (1999) have developed a model for malaria diffusion based on laboratory evidence. Jetten and Focks (1997) built a biological model of dengue fever while Hales et al. (2002) have built a statistical model. Moodley et al. (2003) is an example of a statistical model to study the distribution of schistosomiasis in South Africa. Rabassa et al. (2012) rely on precipitation data to reveal that children's health in Nigeria is related to precipitation events.

METHODOLOGICAL NOTE

The World Health Organization (WHO) identifies two types of models to assess the relation between climate and disease vectors. First, there are biological models based on lab data. These are precisely measured in a lab setting but may not be applicable to the real world.

The other method is to use statistical techniques such as the econometric studies of climate impacts on agriculture.. The weakness of this approach tends to be unobserved variables bias.

Most models use Geographic Information Software (GIS) in which data on climate, vegetation and other geographic characteristics are mapped onto distributions of vectors and diseases. Climate change scenarios produced by the GCM can then be laid on top of the GIS map to study how temperature and precipitation changes would affect the distribution of the disease.

A model that generates socio-economic scenarios is then necessary to study the vulnerability of the population. Ideally, the model should map future changes of population density, income per capita and other indicators of economic and social development. By intersecting socio-economic drivers and diffusions of the disease it is possible to assess the population at risk and to identify optimal adaptation strategies. The cost of the adaptation can then be compared to the benefits of avoided morbidity and mortality.

2.6.3.4 VALUING HUMAN HEALTH

This section introduces methods used by economists to estimate the value of reduced morbidity and mortality. This idea has been mistakenly interpreted as valuing human life. However, it is not a life that public policy needs to value. Generally, what needs to be measured is the marginal value of an incremental reduction in the rate of human mortality or morbidity. How much should society spend to slightly reduce mortality rates?

Some essayists argue that it is immoral to discuss such trade-offs between mortality rates and all other things, but such trade-offs exist throughout our private lives and for many decisions in medicine, public health, and environmental protection. People decide how fast they want to drive on the highway, whether to wear seatbelts, whether to buy fire alarms, whether to smoke or drink, what weight to maintain, and whether to cross streets without cross walks. All of these choices involve small changes in mortality and morbidity rates in return for time, convenience, and money. Weighing such choices permeates our private lives. Society also faces these choices in an array of public decisions. Public policy decisions can reduce mortality rates by a small amount through public health, medicine, food, highway safety, or building safety. The cost of all these measures limits how many of them can be taken. Putting the benefits and costs together identifies which measures are more effective. The primary way that economist's value willingness to pay to reduce mortality risks is to examine wages across jobs with varying risks. Every job has a slightly different risk of dying associated with it. In general, more risky jobs require a risk premium, a slightly higher wage to compensate workers for taking the additional risk each year (see Viscusi and Aldy 2003 for a review of studies in the US and abroad).

A secondary method to value risk is to examine averting behaviour by consumers (Blomquist 2004; de Blaeij et al. 2003). This approach examines the extra cost of safer goods and services against the lifesaving potential. For example, people might buy fire alarms or safer vehicles.

A third approach is to use contingent valuation. People are asked to state how much they would pay for small reductions in mortality rates. One limitation of the use of stated preference for this problem is that respondents have a difficult time understanding what small changes in mortality risk really mean. That is, respondents tend to state the same value for a 1/100,000 chance and a 1/10,000 chance of reducing mortality rates.

One controversial issue with the mortality literature concerns whether or not to adjust for age. The expected lifetime remaining varies a great deal with age. For example, an infant has a life expectancy of 75 years whereas an elderly person who is 70 years old has a life expectancy of 10 years. Should the value of these two mortality rates be the same or should the value of each year of life expectancy be the same?[11] This can have important consequences for public policy because some risks may affect primarily young people whereas others may involve primarily the elderly. Public policy has often decided to use just one value for mortality risks rather than one value for a year of life expectancy. Even though private individuals may place very different values on mortality risks, most societies rely on a single value for everyone within their society.

[11] Aldy and Viscusi (2007) and Alberini et al. (2004) examine the question of whether the VSL should vary with age.

Another controversial issue concerns whether every country places the same value on a small mortality risk. In practice, wealthier countries tend to place higher values on mortality risks. This is consistent with their behaviour as well. One can readily observe that wealthier countries spend more on public health, hospitals, highway safety, fire protection, building safety, etc. than poorer countries. The general rule of thumb is that the value placed on mortality risk is roughly proportional to income per capita (Cropper et al 2011). This does not imply that wealthier countries are in any sense more upright or moral than poorer countries. It merely indicates that they have more income (resources) and can afford to spend more on risk reduction. Some commentators argue that for climate change, a single value for small mortality risks should be used throughout the world. But this is a problematic solution. The average value of the world would be too low for wealthy countries and at the same time too high for very poor countries. Wealthy countries would have to place low values on global climate health risks while spending large amounts to avoid domestic risks from other sources. Similarly, a single global climate value would force poor countries to spend a lot to avoid climate health risks and yet spend very little to protect their citizens from domestic risks from other sources. Values actually vary across countries. The most efficient health values to use are the values of the country affected. Morbidity is often valued in terms of the cost of treatment and the lost wages during the illness. Countries with more expensive health systems and higher wage rates thus place a higher value on morbidity. Comparing different illnesses, diseases that lead to longer periods of sickness are given greater weight. These out of pocket costs are sometimes seen as an underestimate of the total cost of morbidity since they do not reflect the discomfort of each disease. Willingness to pay surveys are sometimes used to try to measure this additional loss of quality of life.

METHODOLOGICAL NOTE

The Value of a Statistical Life (VSL) is the aggregate payment a society would pay to avoid the loss of one statistical life. Although this is sometimes mistaken as the value of a single person's life, it is intended to represent the value of a small change in underlying mortality rates spread across the population. For example, US hedonic wage studies place a US $20 to US$ 60 per year on a 1/100,000 chance of dying at a job (Mrozek and Taylor 2002; Viscusi and Aldy 2003). If 100,000 people were exposed to an additional 1/100,000 risk, that would lead to one statistical death. Summing up these small incremental risks across the population, society would value that statistical death as being worth US$ 2 to US$ 6 million. But this is not the value of a person's life. This is just the value of a 1/100,000 risk spread across 100,000 people.

SUMMARY OF HEALTH SECTOR

Societies make judgments about the value of life whenever they set budgets for life saving activities such as fire protection, highway safety, medical programs, public health programs, and building codes.

Wage studies in the United States imply that a 1/100,000 risk requires a wage premium of US$ 20 to US$ 60 per year. This is translated into a Value of Statistical Life equal to US$ 2 to US $6 million dollars.

The Value of Statistical Life is approximately proportional to the income per capita in each country. Each country should evaluate the Value of Statistical Life consistent with decisions in their society.

2.6.4 RECREATION AND TOURISM

Tourism and outdoor recreation is another major economic sector of the world economy that is climate sensitive. Climate affects recreation and tourism in many ways. Outdoor activities are heavily dependent on climatic conditions: biking, hiking, skiing and swimming all have an optimal temperature range. In some cases climate is the major driver of tourism. People take long-haul international flights to enjoy warmer temperatures during winter and to find snow for winter sports. In some small developing countries, tourism is the main sector of economic activity. A change in adverse conditions might reduce revenues from tourism with major macroeconomic consequences. The opposite is also true: cold areas might become more attractive and generate new revenues for the economy.

Tourism and recreation is also an important measure of the value of ecosystem services. Many internationally known ecological sites are visited each year and enjoyed by admiring visitors. From tropical forest sites, to coral reefs, to vast plains, people visit from around the world to enjoy the flora and fauna of unique sites. Climate change is likely to affect these locations by altering their underlying productivity and gradually shifting their location. Modern conservation techniques need to anticipate these changes and facilitate positive changes and try to limit harmful effects. Rather than taking a purely static view of nature, modern conservation needs to adopt a more dynamic view reflecting that nature itself is dynamic. With climate change, future conservation plans should sometimes facilitate change rather than automatically opposing change. If valuable ecological reserves are to be preserved in a changing world, they themselves must adapt to changing conditions.

A large literature shows that both the demand and supply of tourism and recreation activities will likely adapt to climate change. People will switch from activities that are performed in cold climates to activities that are instead more rewarding in warm climates (Mendelsohn and Markowski 1999; Shaw and Loomis 2008). Instead of the current practice of flying south to find warm climates they might fly north to find cooler climates (Hamilton et al., 2005). Some studies find that climate change would “drive tourists towards the poles and, for those not interested in sea and sand, up the mountains” (Bigano, Hamilton, and Tol 2006). Alternatively, people may seek to preserve the same weather and touristic destinations by changing the season they visit (Perry, 2003; Esteban-Talaya et al., 2005).

Temperature and precipitation may have indirect effects on tourism by changing ecosystems. If existing ecosystems quickly fail because of climate change, tourism based on those ecosystems may diminish. People seeking where new ecosystems might flourish in the future may be new visitors. As species migrate to follow temperature and precipitation changes, ecotourism will eventually follow as well. Some of these changes might be immediate if ecosystems change quickly in new climate conditions. However, it is more likely these indirect ecosystem effects will lag behind climate change and take decades to materialize. Ocean acidification from carbon dioxide deposition in oceans is another potential source of ecosystem change. Ocean acidification will eventually lead to coral bleaching affecting the attractiveness of coral reefs in many parts of the world. Extreme events such as tropical cyclones might also reduce the attractiveness of travelling to vulnerable regions like the Caribbean and the Western Pacific Ocean. Sea level rise may affect coastal infrastructure, low-lying small island states, and beaches sharply reducing their tourism (see Ng and Mendelsohn 2005).

Cross-section econometric studies can be used to estimate the relationship between climate and the choice of recreation and tourism destinations. Cross-section econometric studies would also reveal how tourist operators at different locations have shaped their supply of recreational and touristic activities to different climates. Cross-section studies might also reveal if there is a significant relationship between the climate of the origin and the climate of the destination (Bigano, Hamilton, and Tol 2006).

Intertemporal studies could examine how weather events alter tourism. How do tourists adapt their visits as droughts, heat waves, and cyclones affect specific destinations? Do people make the same trips no matter what happens? Do people find substitutes? How large is disaster tourism where people go to places that experience a disaster?

SUMMARY OF RECREATION AND TOURISM

As climate change causes ecosystems to change, tourism and recreation based on these systems will adapt and be drawn towards places that improve and away from places that deteriorate. Conservation efforts will need to take a more dynamic approach to managing ecosystems in order to adapt to changing conditions. Rather than trying to keep every ecosystem from changing, future conservationists may want to actively manage natural lands to change so that they can keep pace with climate change.

Warmer temperatures are likely to have a direct effect on tourism as well shrinking activities based on snow and cold and expanding most summer outdoor activities. Activities such as boating, swimming, hiking and bird watching will grow while skiing will fall.

2.6.5 EXTREME WEATHER EVENTS

We define extreme weather events to include tropical cyclones, smaller storms, heat waves, floods, and droughts. Each of these can cause major economic damage, lost life, human injuries, and changes to ecosystems. When lives are lost, productive assets are damaged, and human capital is destroyed, the impacts can have lasting consequences.

One characteristic of all extreme events is that they occur frequently across the earth but they have a 'low-probability' of occurring in each specific location. For example, there are about fifty tropical cyclones a year globally, two on average strike the United States a year, but only one strikes New England every ten years. Another feature of these events is that they tend to have large local consequences. This is especially true of major floods and tropical cyclones. A major tropical cyclone such as Katrina can cause a US$ 100 billion of damage. Yet globally, the cumulative damage of tropical cyclones is only US$ 26 billion per year. Because extreme events are so visible, they are often seen as the poster child of climate change. Yet, extreme events are erratic. Not only are they rare, but also they appear to come and go in cycles. It is very difficult to discern small changes in tropical cyclone climatology. One needs very long records of extreme events in order to discern small changes. Unfortunately, such long historical records are not available.

There is a discernible trend in the damage caused by extreme events. Floods, tropical cyclones, and heat waves are all causing more damage today than in the recent past. Some analysts have mistakenly concluded that the increase in damage is a clear indication of more frequent and intense extreme events. However, the increased trend in damage can be entirely explained by the increase in what is in harm's way. Controlling for what is in harm's way reveals no long-term trend in damage. It is also worth noting that there has been a decrease in fatalities from some events, especially droughts. Again this is not due to a reduction in the frequency or intensity of droughts. The reduction in deaths from droughts can be entirely explained by the success of relief efforts (an adaptation) to temporarily feed people during famines. Statistical methods have not yet been able to discern any effect of climate change on extreme events.

In order to measure the effect of climate change on extreme events, scientists have turned to atmospheric models of each extreme event. For example, they have explored the effect of climate on tropical cyclones (Emanuele et al. 2008). This study examined different changes in future possible climates to discern how they will affect future storms. The tropical cyclone research seems to indicate that the frequency of such storms will not change but the intensity of at least the more powerful storm might increase in at least two ocean basins: the North Atlantic and the Northwest Pacific. The extreme event report (IPCC 2011) states "There is low confidence in projections of small spatial-scale phenomena such as tornadoes and hail because competing physical processes may affect future trends and because current climate models do not simulate such phenomena." It is consequently not clear how small storms such as thunderstorms, hail storms, and tornadoes will behave with climate change. However, there is evidence that the strength of cyclones might increase at least in some ocean basins (Emanuel et al 2008). There is also evidence that floods and droughts might increase, at least in some places (IPCC 2012). These changes would increase the damages from extreme events and each is discussed below in more detail. Heat waves are departures from normal temperature. They are measured as unusually high deviations from normal temperature. If climate change increases the variance of temperature or if it skews temperatures towards higher levels, society will experience more abnormally high temperatures and therefore more heat waves. However, if climate change does not alter the distribution of temperature around the mean but just increases the mean, there would be the same number of heat waves in the future as there are today. Climate models do not yet predict a change in the distribution of temperature around the mean. They simply predict the mean will increase. There is consequently no evidence yet that the frequency and intensity of heat waves will change.

In order to value changes in the climatology of extreme events, one must weigh both the changes in probability and in consequence of the extreme events. Relying on data from EMDAT (2010), the World Bank and United Nations (2010) calculate that extreme events currently cause annual damages of almost US$ 60 billion globally. Tropical cyclones cause 44 per cent of this damage and floods cause another 33 percent. If global populations and economies continue to grow as expected, the damage from extreme events would likely double by 2100 simply because there will be a lot more in harm's way. This doubling does not take climate change into account.

DEFINING EXTREME EVENTS

Extreme weather events are low probability – high consequence weather events. They are inherently hard to study because they are rare. They are also hard to adapt to for the same reason. However, there are some effective adaptations to even extreme events..

The primary concern with extreme events is their impact on economic damage, mortality, and morbidity. Economic damage includes losses of private capital such as homes, factories, and farms as well as public infrastructure such as roads, bridges, and government buildings. Losses to ecosystems are harder to evaluate. There is no question one can measure physical changes in ecosystems that are struck by floods and storms. What is ambiguous is whether such changes are natural disturbances and are an integral part of these ecosystems or whether they are manmade and an unwanted disturbance.

There are many ways to adapt to extreme events. One can make investments in precautionary measures such as building sea walls against tropical cyclones or building a safe structure against a flood or tornado. The cost of these precautions must then be weighed against the expected benefit- the probability of an event times the damage the structure avoids. The more rare the event; the lower is the expected value. Countries that face extreme events more often should take more preventive action.

Another way that societies adapt to extreme events is to put in place programs that become effective only once the event occurs. For example, relief programs kick into place once droughts or floods occur. The advantage of such programs is that they incur costs only when the event happens. The costs and the benefits accrue only the event takes place. Of course, the disadvantage of such programs is there is only so much one can do after the damage has been experienced. Nonetheless, relief programs created since the 1970's have been extremely effective in reducing deaths from droughts. Drought warnings provide sufficient time to allow relief programs to head off famine, one of the worst consequences of droughts.

A third important set of adaptations to extreme events involve early warning systems. Climate science has progressed enormously to provide accurate forecasts of coming extreme events. These early warning systems have contributed significantly to a reduction in deaths from storms. People are given adequate warning to take precautionary measures such as fleeing to local shelters and evacuating dangerous lowlands. Mobile capital can also be moved in anticipation of a storm. So airplanes are routinely flown out of the path of storms. Of course, there is no way to move permanent structures so warnings have been less effective at reducing economic damage.

The overall goal of finding efficient adaptations to extreme events is more difficult than with certain changes because of their low probability of occurring. However, there are many adaptation measures that can improve the situation.

2.6.5.1 CYCLONES

A recent report on extreme events (IPCC 2012) has stated, "It is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged." However, "average tropical cyclone maximum wind speed is likely to increase, although increases may not occur in all ocean basins."[12] There may be fewer cyclones, but they will likely be more harmful in some places.

Using a downscaled climate model and a tropical cyclone generator, researchers were able to predict how climate change would alter the global distribution and spatial pattern of tropical cyclones in every ocean basin (Mendelsohn et al. 2012). The cyclone model tracked each hypothetical storm, its intensity, and where it made landfall. Further using a damage function based on storm intensity, population density, and income, the authors could then predict the damage that each storm would cause. The authors then compared the aggregate damages caused by storms in the current versus the future climate. They find that different climate scenarios generate very different changes in tropical cyclones. Cyclones would generally intensify in the North Atlantic and Northwest Pacific oceans but not in the other ocean basins. The higher intensity in these basins would lead to much higher damages. In fact, the model predicts damage would double globally from climate change. A great deal of the additional damage would occur in the United States, China, and Japan. The Caribbean islands would have the greatest tropical cyclone damage as a fraction of GDP.

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[12] "Tropical cyclone is a general term for a strong, cyclonic-scale disturbance that originates over tropical oceans. It is distinguished from weaker systems (often named tropical disturbances or depressions) by exceeding a threshold wind speed. A tropical storm is a tropical cyclone with one-minute average surface winds between 18 and 32 m s-1. Beyond 32 m s-1, a tropical cyclone is called a hurricane, typhoon, or cyclone, depending on geographic location" (SREX, 2012).

One very important adaptation is to make sure that everyone who builds a structure along risky coastlines must bear the cost of that risk. For example, insurance programs should charge much higher rates along risky coastlines for insurance. The rates would reflect the expected damages from living in these particular places. Places with more storms would have higher rates. If owners realized how risky these locations were, they could take measures to reduce the damage. However, if their insurance rates are subsidized, this reduces their incentive to adapt. The US heavily subsidizes flood insurance and it provides generous local relief after tropical cyclones. This helps explain why the US has only 4 percent of global tropical cyclone strikes but two thirds of global damage. In contrast, the American share of global deaths from tropical cyclones is only 0.7 percent because people are not compensated for dying in a storm.

Photo Credit: USAID/UNDP

Sea walls could also be built to protect coastal areas from storm surge. This would be an effective strategy against common low intensity storms. However, the massive storm surges associated with the largest storms would require very tall, strong, and expensive sea walls. Given that high intensity storms will remain rare events (one in 100 years), it is hard to justify such massive investments. Massive sea walls are not needed often enough to justify their cost and their intrusion into everyday life. Yet, over 90 percent of damages from tropical cyclones are in fact from the most dangerous storms. Building lower sea walls to protect against smaller storms will have little effect on the overall damages from tropical cyclones.

Although it may be very difficult to prevent tropical cyclones from causing large economic damage, it is possible to avoid deaths. Deaths per tropical cyclone have been falling for several decades. Early warning systems allow major metropolitan areas to evacuate low-lying areas before storms arrive. Rural populations are able to flee to local safe houses. Elderly and handicapped people can be moved to safer ground.

2.6.5.2 FLOODS

The IPCC 2011 extreme event report affirms, "projected precipitation and temperature changes imply possible changes in floods, although overall there is low confidence in projections of changes in fluvial floods. Confidence is low due to limited evidence and because the causes of regional changes are complex, although there are exceptions to this statement."[13] In other words, changes in global climate patterns will likely lead to both increases and decreases in floods depending upon how local climate actually changes. Because adaptation is inherently local, this makes it difficult to do too much advanced actions to avoid future flooding risk. One simply does not know where the risk will increase and where it will fall far in advance. However, one thing is clear, as the climate unfolds, one should adapt to the actual climate one is experiencing. Local changes in flood risk gradually reveal themselves. It is critical to adapt to these new observed risks. The faster each locality adapts to actual changes in flooding risk, the more effective they will be.

Although overall runoff is proportional to overall precipitation, flooding is a more complex phenomenon. Flooding is commonly tied to exceptional short-term precipitation events. These can be tied to very large phenomenon such as tropical cyclones but sometimes they can be triggered by smaller phenomenon such as thunderstorms in narrow gorges. The flooding outcome from any specific weather event depends on the characteristics of each watershed so that it is difficult to generalize how climate change may affect flooding across a large landscape. Global Circulation Models do not contain the spatial or temporal detail required to do accurate flood forecasting. The climate forecasts of GCM's must be coupled with geographically detailed hydrological models of specific watersheds including features such as snow pack, vegetation, and manmade structures such as development, dams, canals, and levies. In order to assess adaptation options to reduce the impact of floods, several climate change scenarios should be explored to understand how sensitive the results are to alternative plausible climate scenarios. For each climate scenario, one needs to predict the probability distribution of extreme rainfall events. A river-basin hydrology model should then translate each of these extreme rainfall events into a flood of different magnitudes. A damage model should then translate these flooding outcomes to predicted economic damages.

In addition to causing economic damage to private and social capital, floods are also a serious threat to human life. According to international disaster statistics (EMDAT 2010), flooding is the second largest weather related cause of death (only tropical cyclones cause more deaths). Flooding can also be an important cause of morbidity, spreading water borne infectious diseases by contaminating drinking waters. The evaluation of morbidity and mortality losses should be considered in the analysis.

The next step is to evaluate adaptation alternatives. There are various actions one can take at each location to reduce flooding consequences including flood control dams, building higher levies, or intentionally allowing some low valued areas to be flooded. One important lesson in studying river systems is that the sections of the river are all connected so that actions taken in one location have impacts downriver. Building high dikes to protect an urban area may push the floodwaters rapidly downstream leading to more severe flooding below. Allowing rivers to flood relatively low valued uplands lands can slow the river down making it easier to control downstream flooding. Extra capacity in dams can store floodwater-turning water that causes harm into water with long-term benefits.

[13] The SREX defines a flood as the "overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods."

An economic model of the river basin is needed to evaluate each possible adaptation option. Actions that lead to high benefits (damages avoided) at low cost should be pursued. Actions with very high costs and only small benefits need to be avoided. Although this advice is straightforward common sense, it is sometimes distorted by payment structures whereby the federal government pays the costs and local individuals gain all the benefits. From the local point of view, the local costs may be trivial and so projects, which provide sizeable local benefits, look attractive. However, when viewed from an overall social perspective, the high federal costs may make the project prohibitive. As with storms, it is possible to calculate the actuarial costs of flooding in each location. Insurance premiums should be set to equal actuarial costs. This informs private and public entities what risks they are taking by developing the land. Subsidizing flood insurance sends the wrong message by encouraging people to locate in harm's way. Once again this is a maladaptation that only increases damage in the long run. This is a problem even without climate change. Climate change will just make this institutional flaw worse.

2.6.5.3 DROUGHTS, NUTRITION AND FOOD SECURITY

Droughts are periods of abnormally dry weather long enough to cause a serious hydrological imbalance.[14] The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) report states "there is medium confidence that some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions droughts have become less frequent, less intense or shorter […]." For the 21st century "There is medium confidence that droughts will intensify […] in some seasons and areas." Large uncertainties remain because future precipitation is hard to predict especially at the local level. Global Circulation Model scenarios can portray very different patterns of precipitations for the same area. There is also wide disagreement on the distribution of rainfall over time. These uncertainties should be carefully considered when planning anticipatory adaptation to drought. In contrast, reactive adaptations to drought have been proven to be very effective. One of the most harmful consequences of drought used to be the mass starvation that followed the failure of local crops. As incomes have risen, people are now able to buy food when local production fails (a reactive private adaptation). Further, effective relief programs now deliver food to poverty stricken drought areas (a reactive public adaptation).

The technical definition of a drought is a reduction in rainfall compared to what is normal in a region. Semi-arid locations that normally have low rainfalls do not necessarily have more droughts. What happens in semi-arid locations is that droughts are more deadly. Drought in wetter locations may cause a reduction in crop yields. But droughts in semi-arid locations often lead to complete crop failure. Droughts will not necessarily increase in frequency with climate change. But if more areas become semi-arid, the damages from droughts may well increase. The timing of droughts is also important. A drought during the growing season often causes a lot more damage than a drought during the offseason.

[14] The SREX defines a drought as "a period of abnormally dry weather long enough to cause a serious hydrological imbalance. […] A period with an abnormal precipitation deficit is defined as a meteorological drought. A mega drought is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more.


Photo Credit: USAID/UNDP

Droughts affect human health directly and indirectly by disrupting the water supply for human consumption, for agricultural uses, and for industry. In the absence of well-functioning markets or if the population lacks access to markets, a local drought might also become a problem of food security and trigger a famine. This is a crucial point when studying adaptation policies: famines are often determined by the lack of access to food rather than by food shortages (Sen 1981). One of the best adaptation policies to avoid famines is development; economic and social development that guarantees access to food markets. This is the striking message that we obtain by comparing access to food in rich oil exporting states in the Arabic peninsula and in poor least developed countries with much higher average precipitations.

This section considers the adaptations needed to deal with deviations from unexpected shortages of water. Some of the adaptations that increase the efficiency of water use by industrial, agricultural and household users also reduce the impact from unexpected periods with low precipitations. Shifting water from low value to high value uses works as an adaptation to drought. Some other adaptations have instead the primary role of coping with the unexpected nature of the event. For example, precautionary management of water resources and storage systems might be used to preserve water for exceptional circumstances. Dams that store water from year to year can be used to ease the burden of a drought provided there is adequate storage before the drought begins. Storing food grains is another mechanism to smooth out the consequences of drought years. Inter-annual storage can smooth out the local consequences of droughts.

However, one of the most effective ways to reduce deaths from droughts is through international relief programs. By providing food relief only in areas heavily stricken by drought, one can target surplus grain for the most affected people. Drought used to be one the leading causes of death from extreme events in the 1970's but today account for a little more than two hundred deaths per year across the entire globe. Drought deaths have fallen dramatically since the advent of effective international relief programs.

2.6.6 CITIES

An increasingly large fraction of the world population lives in cities. Cities are often quite vulnerable to climate risks because they are often near the sea or rivers. With their large populations, climate risks can often lead to very large damage and many fatalities in cities. Cities will be affected directly by floods, heat waves, cyclones, smaller storms, and sea-level rise. Cities will be affected indirectly by droughts and by impacts on agriculture. It is therefore a high priority that cities adapt to climate change. The benefits of avoided damage can be quite large and the small geographic size of cities can keep adaptation costs low. The methods illustrated in the previous sections to study adaptation apply to cities as well as rural areas, but the results often suggest more actions be taken in cities.

The high density of population and the large amount of infrastructure in cities increase their vulnerability to floods, cyclones, and other violent storms. When cyclones, storms, and floods strike cities they cause noticeably more total damage than when they strike rural areas. Sea-level rise also poses a serious challenge to urban areas because many large metropolises lie in coastal areas or near river deltas or estuaries. Large fractions of valuable assets are at risk of being submerged. The biggest problem with cities is that there is so much more in harm's way including buildings, infrastructure, and people.

Heat waves also pose greater risks in cities than in rural areas. Again the problem is the sheer number of people in harm's way. Many more people die in cities than in less populated areas when heat waves strike.

Of course, this does not necessarily mean that cities are inherently more dangerous than rural areas for the average person. A careful analysis of the EMDAT data suggests that the damage per person from extreme events is lower in cities than in rural areas. Although aggregate damages are higher, the damage per person is lower. This result applies across the board to tropical cyclones, floods, small storms, and heat waves. The results suggest that cities are actually safer per person than rural areas. The hardened structures of cities do a better job of protecting against high winds than the structures in rural areas. Many cities have levees that protect them from sea surges and fresh water floods. Cities tend to have more cooling capacity that protects them from heat waves. Relief programs often attend to problems in the cities before they reach out to the countryside.

But what the analysis does suggest is that there is a very high priority for cities to adapt to climate change. The high density of people and capital in cities make them very vulnerable to climate risks. Adaptation in cities is likely to lead to very large benefits not only to future risks but to current climate as well. The cost of adaptation can be relatively low because of the relatively small geographic size of cities. The economics of adaptation suggest that adaptation in cities should be a very high priority.

CHAPTER 3

GATHER CLIMATE CHANGE SCENARIOS & IMPACT DATA

3.1 PUBLIC AND PRIVATE ADAPTATION PROJECTS

Both public and private adaptation projects to climate change should pass cost-benefit tests. However, when can one expect that private individuals and firms will conduct efficient levels of adaptation without public aid and when is government intervention absolutely necessary? If the market can adapt to some changes entirely on its own, what role does the government have? In general, individuals and firms will invest in private adaptations that make themselves better off. The private sector will make most of the efficient private adaptations without government intervention. Governments should avoid financing projects that have mostly private benefits because at best they would simply replace private investments that would take place anyway. At worst, the government may find itself financing primarily inefficient adaptations with no net social benefit. Government funds should instead be used to finance adaptations that individuals and firms would not provide autonomously. That is, all governments should focus on public adaptations because these efforts otherwise will not take place.

In general, economists have long shown that private agents do not invest, or invest too little, in public goods (Samuelson 1954). For example, markets do not control pollution, protect conservation zones, or preserve the peace all by themselves. Governments must be involved to assure that public goods are provided at appropriate levels. While private goods (for private use) are bought and sold on markets all the time, public goods are not available in market places. There are no clean atmospheres, public parks, or endangered species for sale. Public goods, by their nature, are shared jointly by many people. For example, many inland people will benefit from a large sea wall. However, some people would want it taller and some shorter. Some will have larger benefits than others. It is very difficult to find ways to get people to pay their share of a public good. Markets tend to fail and under provide public goods. Some kinds of climate adaptation are public goods. The sea wall, public health, flood protection, and conservation efforts all benefit many people and are enjoyed by many at once. The market cannot be relied on to provide such public goods. Governments must assume responsibility for providing public goods. However, even public goods must pass a cost benefit analysis to be desirable. The rest of this Chapter illustrates with greater detail the roles and responsibilities of the private and the public sectors.

3.2 THE ROLE OF PRIVATE ACTORS IN ADAPTATION

In order to understand how private actors will respond to climate, one must first understand how climate directly affects individuals and firm decisions. Individuals purchase goods and services in order to maximize their own welfare, subject to their financial possibilities, the information they have and other constraints. The consumption of some goods is largely unaffected by climate. However, the consumption of other goods may be strongly influenced by climate. The choice of food, clothing, and recreation activities is usually very sensitive to climate conditions and individuals can be expected to change their demand of those goods if climate conditions change. Individuals will adapt by changing the composition of the goods they consume. Economic theory, backed up by empirical evidence, suggests that, in general, it is reasonable to assume that they will do this efficiently – i.e. they will change consumption patterns only if the benefit is greater than the cost – given the set of constraints they face.

Analogously, firms purchase production inputs and make production decisions in order to maximize profits, subject to their financial, information and other constraints. Firms will adjust the demand of climate sensitive inputs and the supply of climate sensitive outputs. Firms will respond to technology constraints, to price changes, and to the prevalent enabling environment they find themselves operating in. They will use inputs that are more productive under the new climate and supply output that is in greater demand with the new climate.

The benefits of adaptations are mostly local, from the individual level, to community level, up to regional and national level. For this reason individuals and communities will have the incentive to invest a great deal in adaptation. Private adaptations are likely to proceed without public policy incentives or government involvement. For this reason private adaptations are also called autonomous adaptations.

ADAPTATION: A COMPLEX MOSAIC RATHER THAN A BLANKET

Whether adaptation is private or public, many of the key factors that determine what to do depend on local conditions. Local climate, local climate change, local prices, local markets, and local resources all play a role in determining how each area should adapt. Adaptation therefore looks more like a complex mosaic than a blanket. It is composed of a set of local actions that very across space rather than a uniform sweeping change across the landscape. Both private actors and government agents must pay special attention to whether an action fits local conditions.

Well-functioning markets greatly enhance adaptation capacity. If households increase (decrease) their demand for a specific good the good will become more (less) scarce and prices will respond accordingly. This will cause suppliers to react. With more scarce (plentiful) goods, prices will increase (decrease), and suppliers will try to make more (less) of the good in response. The market reactions will lead to indirect effects of climate on suppliers. Their change in production is a market adaptation. Similarly, if aggregate production falls (increases), goods will become more (or less) scarce and consumers will react by buying less (or more) of the good. In this case, consumers will be affected indirectly through the market leading to a change in the goods being bought and sold in that market.

Markets lead to important indirect adaptations for goods that are traded. When markets change because of adaptation, the impacts of climate change are felt throughout the world, not just in the places where the direct impacts first occurred.

3.3 THE LIMITS TO PRIVATE ADAPATION AND THE ROLE OF PUBLIC ADAPTATION

There are theoretical considerations and empirical evidence to suggest that individuals generally behave in an efficient way, given the information they have and the economic, technological and institutional constraints they face. However, in many circumstances information problems and external constraints do not allow individuals to make decisions that would make them better off. There is a large body of research that shows how seemingly inefficient and irrational behaviour of poor individuals in developing countries could actually be the result of efficient and ingenious adaptations to environments with severe economic, social and institutional constraints (Bardhan and Udry 1999).

Private adaptation does not have limitless possibilities. Private individuals and firms cannot be expected to provide public adaptation. Further, there are circumstances where individuals and firms may not make efficient private adaptation choices:

1. Information problems: if private actors do not know that a new behaviour will make them better off, they may not engage in it. Providing information is an important service of government;
2. Absence of a functional market and weak property rights will lead to perverse incentives. For example, there are reasons to believe that common property resources, which are not well managed currently, will not adapt to climate change. Climate change will make matters worse.
3. Externalities, examples when private decision makers do not bear the full costs of their decisions, can also distort incentives. For example, firms may pollute and damage others. If they are not charged for these costs, they will not take them into account. Climate change can make some externalities worse.

Typically, governments have the primary responsibility of eliminating or reducing the barriers to private adaptations. Projects that address the three broad classes of market failures listed above will spur private adaptation and will also have large positive side-effects on development. Adaptation and development are two complementary strategies that public agencies should strive to pursue jointly (Schelling; Tol 2005; Mendelsohn 2011).

3.4 PUBLIC GOODS

While it is likely that individuals and firms will adapt privately to climate change in order to maximize their own welfare, it is unlikely that they will also provide adaptations, which will mostly benefit other individuals or firms. Private firms will engage in expensive adaptation projects that deliver private returns to their shareholders but they are unlikely to invest in public adaptations that benefit strangers. A large body of theoretical and empirical research in economics shows that firms and people usually do not invest enough resources in projects with large positive benefits to others (Samuelson 1954).

Examples of typical public adaptations are sea walls that would protect everyone behind them, species or ecosystem conservation that many people might enjoy, and mosquito control that might reduce local illnesses to a community. Governments can act on behalf of a heterogeneous citizenry to supply such services. Governments are needed to encourage public adaptations. It is important to note that the reason why governments should play a role is not because these projects require large financial resources but rather because the benefits will be public (shared).

An important special case of public goods involves externalities. Externalities involve costs that agents impose on others but do not pay for. For example, firms may pollute into the atmosphere, which then harms many victims. Mitigating the pollution is a public good because many people would benefit. The market tends to invest too much in activities, which have large negative externalities. Climate change is a primary example of a negative environmental externality.

Private households, firms and markets do not manage externalities well. Without government corrections private markets undervalue externalities (often ignoring them entirely). Environmental taxes and regulations are typical corrections used to reduce the negative externalities from pollution. Similarly, subsidies are often used to promote goods and services that have positive externalities. Both taxes and subsidies should be set so that private decision makers take into account all the costs and benefits of their actions.

PUBLIC GOODS

What are public goods? Public goods are jointly consumed goods where many people simultaneously enjoy a good (for example a radio program, rules of law, biodiversity, or national defence). Markets can deliver public goods when all consumers are alike (tennis club), but tend to under provide public goods when consumers are heterogeneous. The provision of public goods is one of the key roles of government.

3.5 INFORMATION PROBLEMS

It is possible that individuals and firms miscalculate the costs and benefits of adaptation because of lack of knowledge. Public agencies have a key role in informing private individuals and firms about climate change risks, vulnerability and possible actions available to reduce their vulnerability. Information is a public good. It benefits everyone once it is known. It makes sense that governments provide important information about climate, its consequences, and how one can adapt. Public agencies should be involved in the process of knowledge circulation, by making all the data that could help private individuals and firms to adapt easily accessible. However, in many instances, public agencies should also be involved in knowledge creation. They could sponsor climate data collection, information on risk and vulnerability; the downscaling of global climate change scenarios and the development of decision-making tools capable of dealing with large uncertainties associated with future climate change scenarios. Available data should become publicly available to support both public and private decision-making. Note that information problems do not require heavy-handed regulations or taxes to induce desired behaviour. If the problem is information, it is sufficient to publicize the missing data.

3.6 OTHER MARKET FAILURES

Lack of access to markets and market distortions reduce the capacity of individuals to adapt to climate change and should be reduced to a minimum. For example, agricultural trade restrictions may force individuals and firms to deviate from their efficient consumption and production choices. Lack of access to markets for inputs might reduce adaptation possibilities as well.

Individuals and firms that have no access to the capital market will not be able to borrow to make capital investments to adjust to climate. Poor credit markets tend to increase interest rates. With high interest rates, firms and individuals focus only on short-term costs and benefits and tend to ignore long run impacts. This can impede long-term adaptations to climate change.

Efforts to help the affected households, however, should be directed at eliminating the root cause of the problem rather than directly paying for adaptation. Providing access to capital markets and secure property rights is an example of a win-win solution. It improves conditions in the current climate and it provides incentives to improve long-term conditions.

MARKET FAILURE

Market failure occurs when individuals and firms do not get the right signals or incentives through prices and therefore make poor decisions. For example, if the government subsidizes weather insurance – farmers get the misleading signal that such risks have a low price, encouraging people to farm in riskier locations. Similarly, subsidized flood and hurricane insurance would encourage homeowners and developers to choose flood prone and risky locations.

In some cases, market distortions might induce private individuals to excessive risk taking. For example, subsidized insurance in areas prone to extreme weather events induce individuals and firms to locate productive assets in risky locations. The price of the insurance is low making it cheap for the private individual to live there. When a disaster strikes, the entire society pays for the additional cost, not the person taking the risk. The overall result is that damages increase because there is more in harm's way. Well-functioning insurance markets would have high premiums in risky locations signaling the high cost of living there. Private individuals and firms would see the high price of the risk and take it into account when choosing locations.

Many firms and individuals in developing countries lack private property rights. For example, many farmers till land, graze animals, and harvest trees on common property. Although there are some rare examples of efficient community organization of common property, they tend to involve very low levels of investment into the land. With modern agriculture, livestock, and forestry methods, common property tends to lead to underinvestment in the shared natural capital. Each household obtains a large private reward from harvesting the natural capital but they are reluctant to invest in that natural capital because they must share the resulting benefits with the other users. There is limited incentive for private actors to make any capital investments to adapt to climate change. Climate change threatens to alter and harm a great deal of common property in the low latitudes. It is not clear that individuals and firms can protect common property efficiently. The problem is that the cost of adaptation is born by each person but the benefits are shared across everyone with latitudes. With resources for publicly financed adaptation being scarce, governments may want to focus their resources on adaptations that the private sector will fail to do. In this context, there are two primary roles for Government. One is to address barriers to efficient adaptation that might plague the private sector. Second is to manage adaptations that are public in nature (involve public goods).


Photo Credit: USAID/UNDP

SUMMARY OF KEY MESSAGES

Private adaptation is likely to proceed without any public policy incentives or government involvement. Markets will encourage efficient private adaptation.

But:

- **Markets will under invest in public goods;**
- **Markets may need to be supported with information;**
- **Market distortions such as externalities need to be addressed by government.**

Public agencies should primarily use public funds to supplement not substitute for private adaptation; they should

- **Finance and organize public adaptations (projects with shared benefits such as public health, conservation, and extreme event protection);**
- **Finance the creation and diffusion of information;**
- **Reduce market distortions and strengthen property rights to increase private incentives to adapt efficiently.**

Photo Credit: USAID/UNDP

CHAPTER 4

CALIBRATE AND RUN THE MODEL

This chapter explains how to value both market and nonmarket goods. The chapter reviews the major tools that economists use to place monetary value on goods and services. Valuing market goods is relatively straightforward. The bigger challenges come with valuing nonmarket goods.

4.1 THE VALUE OF MARKET GOODS AND SERVICES

Climate change will affect the supply and demand of both consumption and investment goods. For example, climate change will change agricultural output and extreme events will affect infrastructures and other capital goods. If goods are traded in markets, prices provide precise measures of marginal value. Small changes in quantities of market goods can be valued using their price. Large changes in quantities of goods, however, cannot be valued using prices. As quantities change, their marginal value changes. For example, a large increase (decrease) in the quantity of a marketed good will lower (raise) its marginal value. One can see this in everyday life. As a good becomes very plentiful, for example, as seasonal fruit starts to get harvested, the price falls. When the same good is scarce, its price can be quite high. The price of summer fruit is often quite high in wintertime.

In order to value a large change in supply, one must measure the value under the demand function from the initial to the final quantity. This area effectively measures the change in marginal value of the good as the quantity changes. Economists call this area the consumer surplus. Non-marginal changes of goods and services should be valued using consumer surplus. There are two accurate estimates of the value of investment goods, the market price of the investment good and the sum of the discounted values of future annual revenues from the investment good. The market price is what the good would have sold for in the market place. The price would take into account the age of the good, its condition, and future promise.

Similarly, the discounted sum of future annual revenue would also take into account these characteristics. Older investment goods (such as cars) would have shorter expected remaining lifetimes and so fewer future years to sum. Goods in poorer condition would yield lower annual returns. Goods providing services no longer wanted (gas guzzlers) would have less annual value.

A less accurate estimate of investment value is replacement cost. This is the cost of buying a brand new good to replace the old one. If one is replacing a brand new investment good, the replacement cost is an accurate assessment of its market value. However, replacement cost is an overestimate of goods that have depreciated with age. Insurance contracts that use replacement cost consequently have higher premiums since replacement cost overestimate true values.

4.2 THE VALUE OF NON-MARKET GOODS AND SERVICES

Although it is harder to measure the marginal and non-marginal values of nonmarket goods, nonmarket goods are valued by people just as market goods are. Just because they are not traded does not mean that they are not valued. Empirical evidence about the nature of nonmarket values suggests that they are very similar to market values. Some nonmarket goods are more valuable than other nonmarket goods (for example, world heritage sites tend to be more valuable than local parks). As people get more and more of any one nonmarket good, they tend to place a lower marginal value on that good. For example, as overall water quality improves, people will pay less for another increment. Values tend to be sensitive to income. Wealthier people generally are willing to pay more for nonmarket goods just as they are for market goods. Values vary across individuals for a host of personal reasons. Some people would pay more to preserve an eagle, others a bear, and yet others a wolf.

The problem with valuing nonmarket goods is that they are harder to measure. Whereas market goods have observed prices to measure marginal value, nonmarket goods have no observable prices. There are no observed prices of air pollution, ecosystems, or beaches. Administrative programs such as cap and trade programs for pollution have internal prices that can be observed, but these are determined by administrative rules, not complete markets. Parks and beaches have entrance fees but they are largely arbitrary. In the absence of markets, it is also harder to estimate the demand function for nonmarket services. How much do marginal values fall as citizens get more nonmarket goods or services?

In order to include nonmarket goods and services into cost benefit analysis, it is necessary that they be valued. That is, physical units of these services need to be monetized. One could use arbitrary values (or your own personal values) to place dollar values on each service, but then the cost benefit analysis itself becomes arbitrary. In order to include nonmarket goods and services, one must determine the value that society places on these services.

Over the last forty years, economists have developed a large number of methods that estimate the economic value of non-market goods. The methods can be grouped in two broad categories: behavioural methods (revealed preference) and attitudinal methods (stated preference). This Chapter provides an overview of these two broad classes of methods (for a review of the literature see Mendelsohn and Olmstead 2009).

4.3 REVEALED PREFERENCE METHODS

Revealed preference methods are preferred by economists over stated preference methods because they rely on observed behaviour of individuals and firms rather than on what people say they would do under hypothetical circumstances. The methods measure the implicit values consistent with the observed behaviour of individuals and firms. For example, the value of outdoor recreation sites can be estimated by studying how much travel cost (how far) people drive to a particular site. The travel cost is the price of a visit, the marginal value of a visit. In order to estimate the demand for visits, one can examine how visits change depending upon how far a person is from the site.

Some non-market goods provide inputs to market activities. The value of these goods can be estimated by observing the net revenue from the market inputs. For example, tropical forests provide a host of non-timber forest products. The value of these products can be estimated by looking at the net revenue from collecting these natural products from the forest. This stream of net revenue is one of the values of the forest.

Sometimes nonmarket goods enhance a market good. For example, local parks enhance the value of nearby residential and commercial properties. One can measure the value of the park by measuring how much property values are elevated because of proximity to the park. The premium for proximity is the value of the park to each property. The total value of the park is then the sum of all these premiums across all the affected properties.

In principle, one can value local parks, air quality, climate, and noise all be seeing how they affect the observed prices of nearby properties. Economists call these methods "hedonic models" by economists. The application of these methods to measure climate has also been called the Ricardian method (Mendelsohn, Nordhaus, and Shaw 1994).
Hedonic models can also be used to estimate the economic value of human life. People tend to be paid higher wages to take on more risky jobs. By observing how much higher wages must be to for jobs that have slightly higher mortality rates, one can measure the marginal value that people place on small increments in the mortality rate. This is a very important method to value health risks.

Values depend on local contexts. Wealthier countries tend to have higher values across the board for nonmarket services. Some countries place higher values on specific services than others. For example, Americans have decided that the bald eagle is their national symbol and so they probably place a higher value on protecting this specific species than other countries. Ideally, one would undertake these valuation methods in every country in order to measure the values specific to that country. Of course, sometimes this is not possible. The next best alternative is to collect values from nearby studies from other countries and adjust the values for income. For many nonmarket services, it is reasonable to assume that nonmarket values vary across countries in proportion to per capita income.

REVEALED PREFERENCE METHODS

Economists favour revealed preference methods to stated preference methods as they rely on observation of actual behaviours by economic agents. Revealed preference methods are econometric in nature and include:

a. Travel Cost Method: Used to value recreational value of large natural landscapes or cultural sites. The core idea is to use the fact that economic agents are willing to pay for their travel to and stay at a given site thus providing some indication of their valuation of it.
b. Hedonic Method: Goods are a collection of characteristics and economic agents pay for the entire collection. Thus, when buying a house, an economic agent implicitly reveals his/her valuation of many characteristics including environmental ones such as level of noise and quality of air.

In order to generate correct estimates of the value of non-market goods, travel costs and hedonic methods must all control for other likely reasons why market values vary. For example, hedonic property studies must control for the qualities of each house. Hedonic wage studies must control for other differences across jobs besides just risk. Travel cost studies must control for other reasons people visit besides just the destination.

4.4 STATED PREFERENCE METHODS

Stated preference methods (contingent valuation) use surveys to estimate the value of non-market goods (see, Portney 1994; Hanemann 1994; Diamond and Hausman 1994). For a review of best methods to use in conducting contingent valuation see Arrow et al 2001. Researchers ask individuals how much they are willing to pay to enjoy a good or to preserve its existence. Stated preference methods can be used to value existing goods – i.e. natural parks that already exist – and hypothetical goods, for example, a new natural park.

Stated preference methods have also been used to assess the economic impact of major environmental disasters such as the impact of the Exxon Valdez oil spill on the ecosystems of Alaska (Carson et al. 1992).

One problem with stated preference methods is that the values that individual's state they have can be different from the values that motivate their behaviour. Respondents often provide "socially correct" values to make themselves look better or to simply hide their own values.

STATED PREFERENCE METHODS

Stated preference methods ask economic agents directly for their valuation of a given non-market good or service. The reliability of this set of methods has been called into question and a vast literature exists that helps to reduce the biases in the answers provided. Importantly, stated preference methods are the only way to find out the value economic agents place on what are called non-use values of non-market goods.

A second problem with stated preferences is that people appear not to take their own budgets into account when stating values, especially for goods that they do not usually purchase. Stated preferences are less sensitive to income than people's purchasing habits would suggest. Sometimes people state values that are wildly out of proportion to what they can afford to pay. Often, they state values for specific things, which are simply representative of a broad concern. For example, they may value a specific species in a specific location as representative of a broad concern that they have with species conservation. The value that they would pay for the entire class of goods may not be much more than what they offered for that specific case. For example, they would not pay as much for every species in every location that they offered for the specific case in the survey.

A third problem with stated preference methods is that it is very important for the surveys to be very specific about what is being valued. The survey needs to contain a lot of information about the good being questioned. When questions are vague, people tend to fill in the details with their imagination. It is hard to interpret the results of such questions because people have effectively answered very different questions.
A fourth problem with attitudinal surveys is that it is easy to bias questions by phrasing them slightly differently and including information that will sway the respondent to provide higher or lower values. For example, one may be interested in valuing the environmental damage caused by the Exxon Valdez oil spill. One could ask the question from a national security perspective emphasizing the importance of domestic oil supplies and lower gasoline prices. Or one can ask the question emphasizing the wealth of the company that owns the boat or the inebriated condition of the captain. The damage to the environment caused by the spill is the same but the different questions would lead to wildly different responses.

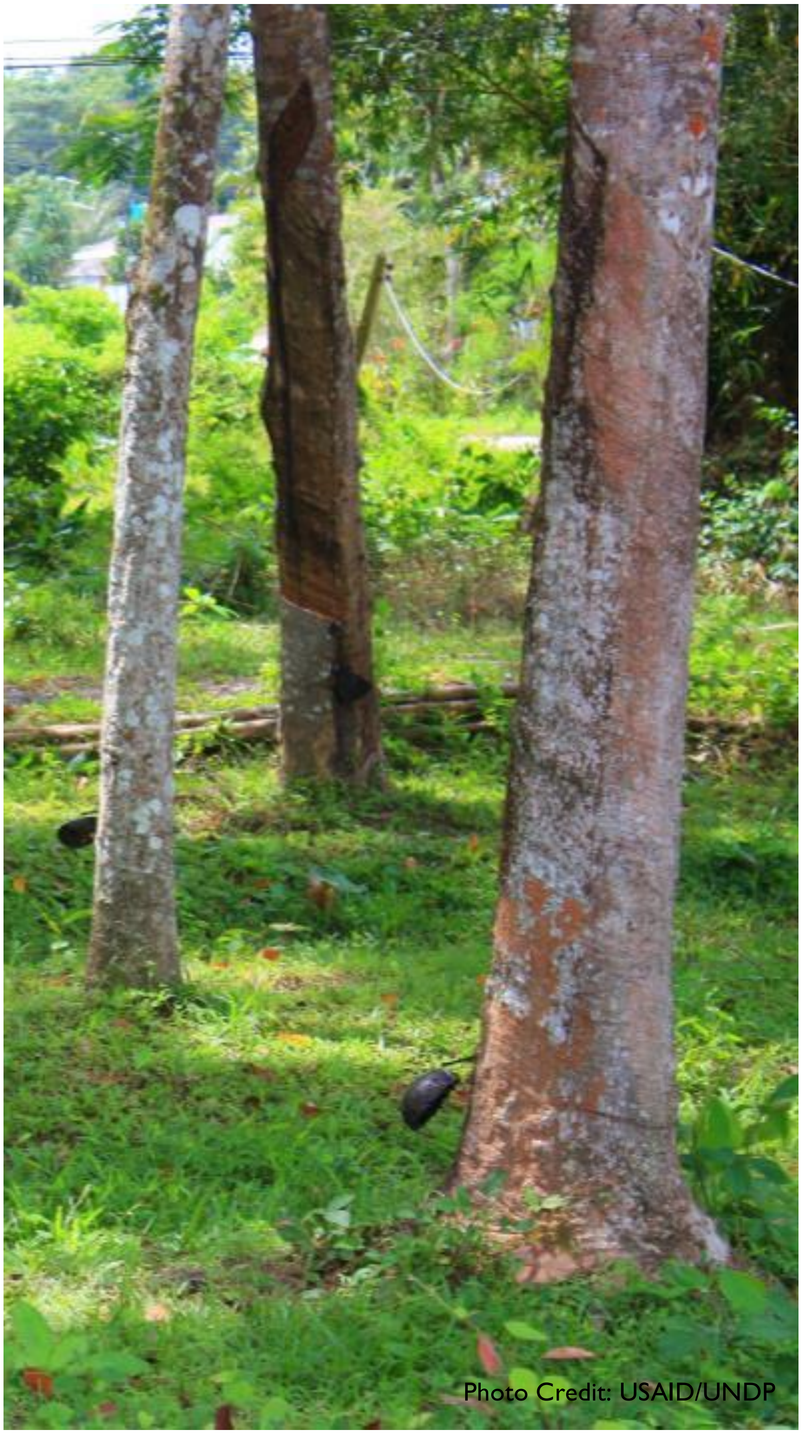
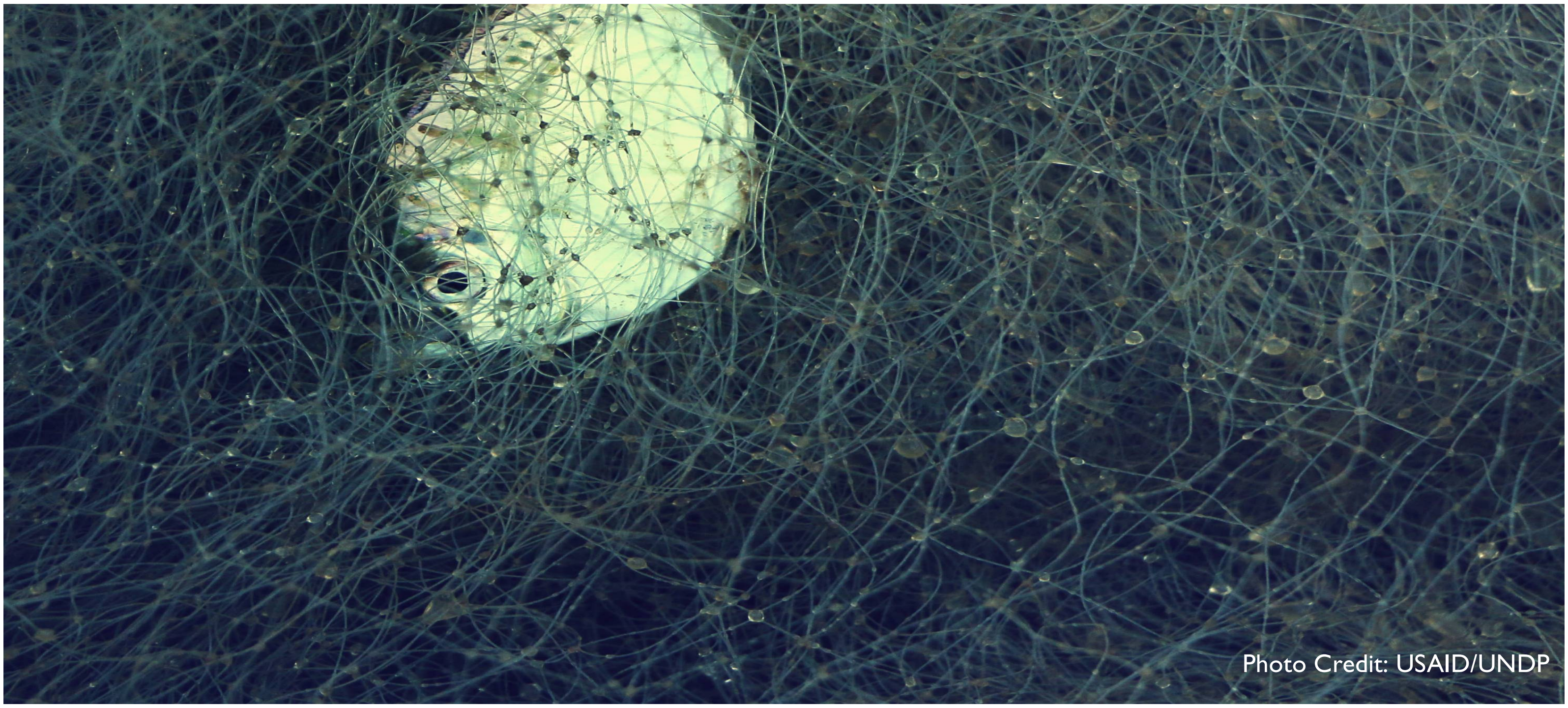


Photo Credit: USAID/UNDP

These problems are relevant for goods, which the respondent is not familiar with purchasing. Attitudinal surveys are consequently a reliable approach for valuing market goods and potential market goods. However, they are very vulnerable to these problems when considering non-use values. It is the application of attitudinal surveys to measure non-use values that reveals the biggest flaws in the approach.

Using attitudinal surveys, people can be asked to either value what they would pay (willingness to pay -WTP) for a good or service or they can be asked how much they must be compensated (willingness to accept - WTA) if they lose the good or service. The literature reports that WTA responses are on average seven times higher than WTP responses (Horowitz and McConnell 2002). Only WTP responses are similar to behavioural values. It is still unclear why these values are so different. But it is clear that WTA responses are biased upwards and the approach should not be used.

This is not to say that stated preference surveys cannot or do not provide useful results. New research work has looked to address the problems outlined above (e.g. see Carson, R. T. & Groves, T. (2007) and Herriges, J., Kling, C., Liu, C., & Tobias, J. (2010). The overall reliability of attitudinal surveys seems to be tied to how familiar people are with the good being valued. When people are asked about things that they have a lot of experience with, they tend to give reliable answers. However, when people are asked to value things they know little about, the answers reflect this ignorance and have very low reliability.



CHAPTER 5

CALCULATE THE NET BENEFITS OF ADAPTATION

This Chapter provides an introduction to cost-benefit analysis and offers practical guidance to assess adaptation projects. The methods discussed in this Chapter can be applied to single projects and to build portfolios of projects in an efficient way. They can be applied to assess investments in specific adaptations to climate change. However, cost-benefit analysis of adaptation projects becomes increasingly difficult as the time frame under consideration becomes longer due to large uncertainties about future socio-economic variables and local climate change. This Chapter addresses how to deal with those uncertainties within the context of a cost benefit analysis. Cost benefit analysis is also questionable as the scope of a program becomes big enough to change prices. When programs are large enough to change input and output prices, one must move to the more long term sectoral analyses.

The objective of cost-benefit analysis is to compare the economic benefit and the economic cost of a single project. As we elaborate later, costs and benefits are not limited to just market goods and services but also include environmental and other social impacts. Only projects that have benefits greater than costs increase welfare and deserve to be pursued. If we think of a project as a series of smaller actions, each with its own cost and benefit, we want benefits to exceed costs for each single action. For example, the construction of a sea wall can be thought of as a project in which several layers of protection are added one on top of the other. Each additional layer must be subject to cost-benefit analysis. One would continue to raise the structure as long as the marginal benefit of more height outweighed the marginal cost. This process logically ends when the marginal benefit just equals the marginal cost of the last increment. After that, the cost of more height would start to outweigh the benefit. The same logic applies to sizing canals in an irrigation project. The canals should be made wider as long as the marginal benefit exceeds the marginal cost. One has arrived at the most efficient size when the marginal benefit finally equals the marginal cost.

MARGINAL COSTS AND BENEFITS

Marginal cost is the additional cost incurred for producing one more unit of a good. Marginal benefit is the additional benefit incurred for consuming one more unit of a good.

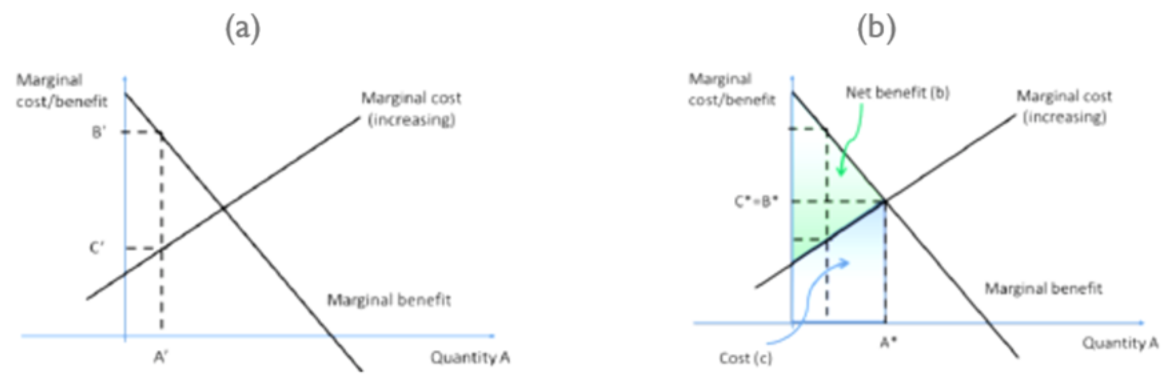
If the market or government provides enough services so that marginal cost just equals marginal benefit, they will maximize total net benefits, This is the social objective of both market and nonmarket activities.

Economists define "marginal costs" as the incremental cost of adding one more unit of input. Marginal costs often increase as more units of a good are supplied to a project. For example, the cost of a sea wall tends to increase with the square of its height. Higher sea walls require ever-wider bases and a lot more volume of material. However, there can be circumstances where marginal costs fall with size. Economies of scale sometimes allow bigger facilities to be more efficient. For example, power plants tend to have economies of scale, which allow very large plants to generate electricity more cheaply than smaller plants.

Economists define "marginal benefits" as the incremental benefit from increasing output one more unit. Most people feel that marginal benefits decline as they get more of any good. That is, as one single good becomes ever more abundant, one more unit tends to have less value compared to other things that are still scarce. The value of many inputs to production processes also tend to decline. For example, adding fertilizer or water to crops initially has a high positive impact on crop yields; but the marginal benefit declines as more is added. Sometimes, benefit functions can be hill-shaped. For example, the yields of many crops tend to have a hill-shaped relationship with temperature. There is a specific zone where temperatures are just right for a crop. But if temperatures get much colder or much hotter, yields fall. In this case, warmer temperatures generate marginal benefits as they go from too cold to ideal but then they become marginal damages as they go from ideal to being too hot.

Efficiency requires that the marginal cost of any single good provided in the project be equated to its marginal cost. That is, one would continue investing in more and more incremental steps until the final step equates marginal cost and benefit. Panel (a) of Figure 5 depicts the marginal cost and benefit of a generic good A for a generic adaptation project. Let us assume that a decision has to be made on whether to provide an amount of good A equal to (A'), as depicted in panel (b) of Figure 5. In a standard economic analysis, this would be considered non-optimal because the marginal benefit (B') is higher than the marginal cost (C'). The outcome could be improved by providing more units of A. Panel (b) of Figure 5depicts the efficient solution when (A*) units of good A are provided, marginal cost (C*) is equated with marginal benefit (B*). In panel (b), the outcome is also non-optimal because the marginal cost of the last unit far exceeds the marginal benefit. This case could be improved by providing less of A. Panel (d) of Figure 5 depicts the efficient solution: marginal cost is equated with marginal benefit. It is not possible to increase welfare either by supplying more units of A or reducing the supply of A. The aggregate cost is measured by the area underlying the curve of marginal costs. The total benefit is the area underneath the demand function. The net benefit is the area between the marginal benefit function and the marginal cost function. Efficient adaptation does not require that all negative (positive) impacts are neutralized (maximized). Reducing expected impacts to zero might require providing an amount of adaptation beyond the socially optimal level (of Figure 5). Leaving residual damages can be an optimal economic decision if eliminating the remaining damages requires society to spend far higher costs than the damage removed. This is counterproductive and actually makes the greenhouse gas problem more costly to society, not less costly.

Figure 5. Cost-benefit analysis



Notes: panel (a) illustrates a case where too little of good A is produced, A'. The marginal benefit, B', is higher than the marginal cost, C'. Panel (b) illustrates that the optimal provision of good A is A* where the marginal benefit, B*, equals the marginal cost, C*. The net benefit of moving from A' to A* is the area underneath the demand function but above the marginal cost function.

Sometimes marginal adaptation costs are higher than marginal adaptation benefits for every possible adaptation. In this case, the welfare-maximizing decision is not to adapt at all. For example, protecting against flooding may require a levee. In some rural areas, the cost of each part of the levee may be more than the benefits of flood protection to the farms. If that is the case, it may be best not to build any levees at all.

Some climate adaptations involve negative externalities. For example, increasing fertilizer may help a farmer offset some of the production losses from climate change, but some of that fertilizer may enter nearby streams and damage water quality downstream. The farmer is not likely to be concerned about these damages when considering applying the fertilizer and so applies too much. The government could correct this externality by charging a tax on the fertilizer equal to the downstream damage. The farmer would still ignore the externality but by responding to the tax, the farmer would choose the socially desirable level of fertilizer.

EXTERNALITIES

Externalities are phenomena that matter to society but are not priced in a market and so are not taken into account by market actors. Markets spend too little resources controlling harmful externalities (such as pollution). Governments need to provide incentives to properly take externalities into account. These include price instruments such as taxes on pollution as well as quantity regulations simply limiting the magnitude of the externality.

5.1 ESTIMATING THE COSTS

Figure 5 uses stylized marginal cost and benefit curves. Practitioners in public agencies need to gather information on the cost of every aspect of the adaptation project. Cost-evaluation methods developed for other kinds of investments can be used also for adaptation projects. Costs include all budgeted items such as labor, machinery, and inputs. But costs can include items not explicitly in the budget such as the time an owner might spend on the project. Costs can also include offsite effects such as pollution damage or damages to a watershed. The timing of costs is also going to be important. The cost accounting should pay attention to the costs incurred each year of the project.

5.2 ESTIMATING THE BENEFITS

For long-lived projects, estimating the benefit of adaptation projects can be more complicated than estimating costs because one must value impacts far into the future. This is difficult because it is hard to foresee how many factors including climate but also technology and prices, may be different in the future. Future estimates tend to be uncertain. For example, no one knows future weather. Climatologists have sophisticated models to predict how climate might change over time but even these models become more uncertain the further into the future one looks. One can adapt to the current climate easily enough but it is much harder to adapt to a future uncertain climate. A first step in the path to adaptation, however, is to make sure that society has adapted to current climate. As climate changes, society must continue to change and adapt. But how much adaptation can be done as a reaction to observed climate change and how much adaptation must be done in anticipation of future climate change? Cost benefit analysis can shed some valuable light on this question by examining the benefits associated with each approach.

With reactive adaptation, one acts only after it is clear that the climate has changed. The advantage of waiting to see how climate changes before acting is that the climate change is known. The benefits of the adaptation are therefore not uncertain. The disadvantage is that there can be a delay between when climate changes and when adaptations take place. The advantage of anticipatory adaptation therefore is that the adaptations can begin in advance and so be in place just as the climate changes. The problem with anticipatory adaptation is that future local climate change is uncertain. It is hard to know when future temperatures will be 1 °C warmer. It is hard to know whether future precipitation will fall or increase. There are consequently few adaptation choices that are obvious in advance. Clearly society would want flexibility so that it can respond to climate change no matter what happens. But sometimes flexibility is more expensive. Delaying decisions until uncertainty is resolved sometimes forces one investing only in short run and not long run solutions. For example, a household may be considering increasing cooling to adapt to uncertain warming. While uncertain, they may hesitate to invest in cooling capacity such as efficient central air conditioners. Instead they may choose to run less efficient wall air conditioners until they are certain about the warming. This will cost them more in the short run but preserve flexibility. Adaptation decision makers must weigh flexibility against its cost.

CLIMATE UNCERTAINTY

The weather is inherently uncertain. Even climate models depict weather using random number generators. Climate, in contrast, is average weather, usually defined over a thirty-year time period. Climate is much less uncertain. Vulnerable sectors consequently have adopted many adaptations to climate even though they remain vulnerable to weather. For example, farmers choose crops that tend to behave well in each climate yet local annual yields continue to vary with local annual weather conditions. If farmers could get reliable predictions of next year's weather, they could make far more adaptations to weather itself. However, weather predictions remain too uncertain to make many of these adaptations worthwhile.

Adaptation to climate change requires new behavioral adjustments to a long-term change of mean climate and the variability of weather. The benefits of an adaptation project can therefore be assessed only on a very long-run time horizon. For example, if the future climate in a region was predicted to become more semi-arid, it may well make sense to invest in an irrigation scheme to shift rain-fed cropping to irrigated cropping when this change occurs. One climate model may predict that this will happen in 2020. However, a second climate model may predict the area will become wetter by 2020. If one builds the irrigation project today, it will have high benefits if the first scenario occurs but very low benefits if the second scenario unfolds. Given the two disparate outcomes, the expected benefit is modest. In contrast, if one waits until it is clear which of the two scenarios actually will occur, then the society can build the irrigation project if climate turns out to be dry and look at other investments if the climate turns out to be wet. The delayed reactive adaptation is more flexible and will quite often be more beneficial. A key adaptation consideration is timing. Done too soon, the adaptation can be ineffective and more expensive. Done too late, there may be damage that could have been avoided.

In cases where the period in question is more near-term (under five years), the question is whether a specific adaptation option improves outcomes given the current climate. Short run adaptations should make people better off in their current climate. Forecasts of future conditions may not be relevant. If the project can be justified for what it does in the short run, knowing the current climate is sufficient.

Projects which provide goods/services over a long period of time must consider climate outcomes over the lifetime of the project. Such projects should not be based on the current climate alone, as they will be affected by climate change. Cost benefit analysis will encourage decision makers to take future outcomes into account as well. How important the future outcomes are depends on the length of time they apply and how important they are relative to immediate outcomes. One must also evaluate the future benefits of the project in possible new climates. This requires a more elaborate analysis. For near term benefits, one would still rely on observations of current climate. However, to measure the future benefit, one would need to examine what may happen to climate and other factors in the future. Such type of projects would require the following six-step process to estimate the net benefits of adaptation:

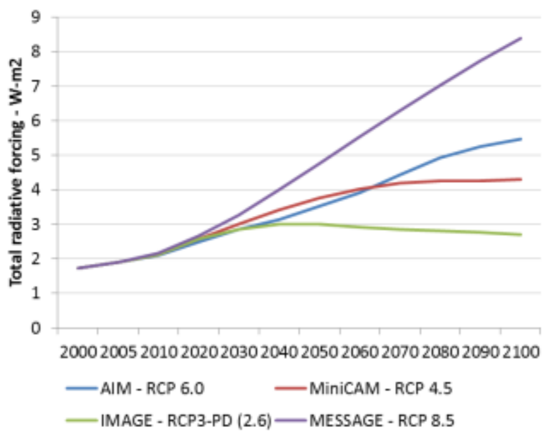
1. A set of climate change scenarios: Given likely emission rates in the near future, one should examine a set of climate change scenarios from different GCMs. Each set should be considered a possible outcome. The expected outcome of acting today is the average of the outcomes of all the models. By examining what happens across a set of models one can reveal the range of possible outcomes, this is the climate uncertainty that the project faces. What is especially important to adaptation decisions is the uncertainty surrounding the local climate forecasts. The period of time that is relevant for each decision depends on the length of the project. For example projects likely to last only twenty years should examine climate scenarios over the next twenty years. Similarly, projects that are expected to last for fifty years, should examine fifty years of climate. If there is very little climate change over that period, the project can focus on the current climate. But if some climate models predict very large changes, these forecasts must be taken into account. The more agreement found amongst the climate models about how future local climate will change, the more adaptation could be designed around that specific climate outcome.
2. A scenario of environmental consequences: What other factors may be different in the future? For example, one might consider a water project such as a dam or an irrigation project to help with a reduction in rainfall to an agricultural region. However, in addition to the change in precipitation, there may also be a change in temperature, both of which will change the demand for water by farmers. Changes in temperature or precipitation can also change river flows (the supply of water). In this case, climate change causes changes to both the supply and demand for water. The project in turn must take both changes into account to determine whether it is a good adaptation.

3. A scenario of socio-economic changes: How would other factors that might affect the benefits of a project change over time? Climate change will occur in the future. What will the economic sector look like by then? What is likely to happen to the sector because of population growth, economic growth, urbanization, and technical change? For example, will there be more development along vulnerable coastline? Will crop yields increase because of technical change? What will be the demand for different ecological services in future periods?
4. Calculate the stream of benefits: What are the benefits each year of this specific project over its lifetime. The stream of benefits of the project should be calculated using the prices and other characteristics applicable in each time period. The annual benefit of the project is the annual value of the change in outcomes with the project versus without the project.
5. Calculate the cost of the project in each period. Some costs for capital might fall heavily in the beginning of the project, for example, to construct a dam. Other costs will continue for the lifetime of the project such as operating costs and maintenance costs.
6. Compute the present value of the stream of costs and benefits. The present value is the sum of the discounted annual values. The values in each year are discounted to make them equal across time. The "discounting" changes all future costs into current costs so they can be added with each other. The discount rate or interest rate is the price of time. Projects with net benefits (benefits exceed costs) are considered desirable by this process. From an investment perspective, they earn the market rate of return. This is important as society decides how to allocate scarce capital across both market and nonmarket resources.

5.3 DATA AND OTHER RESOURCES

Data on climate change scenarios is publicly available from the IPCC data distribution center (www.ipcc-data.org). A large dataset groups all scenarios run by GCM and used in several IPCC assessment reports. Data is freely available but usually needs to be processed before it can be used in a cost-benefit analysis. If the project needs climate change scenarios with high geographic resolution downscaling techniques of large GCM outputs or regional climate change models can be used. In both cases it will be necessary to use the expertise of a climatologist. A new family of emission scenarios has been recently released and is being used by GCM's to generate the next generation of climate change scenarios (van Vuuren et al. 2011). The new emission scenarios are called Representative Concentration Pathways (RCP). Representative Concentration Pathways have been built using four integrated assessment models (IAM) under four alternative long-term GHG concentration targets. Note that the RCPs are designed to provide distinctly different radiative forcing inputs into climate models. They are not representative future outcomes of emissions. Policy analyses must be very careful not to present them as realistic scenarios. The only scenario that is close to a zero mitigation scenario is RCP 6.0.

Figure 6. Total radiative forcing in the Representative concentration pathways (RCP)



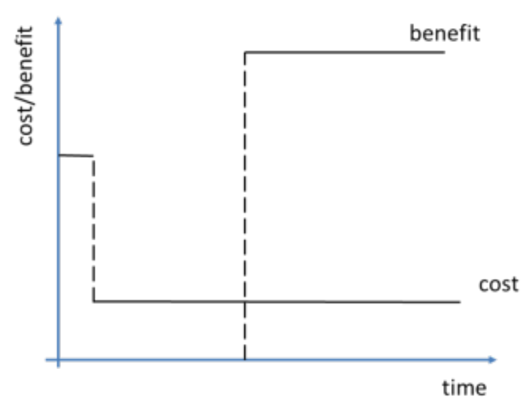
Notes: total radiative forcing fewer than four alternative emission scenarios. Each concentration pathway was elaborated by a different integrated assessment model. Source www.iiasa.ac.at.

Impact models are usually not freely available. In order to use an impact model it is often necessary to involve researchers that have developed specific types of models for analysis specific issues. Information on impact models for specific sectors is provided in Chapter 2 of the toolkit.

Socio-economic scenarios can be developed by economists or experts in other social disciplines. Several socio-economic scenarios developed by the IAM are also freely available. The international scientific community has used for many years scenario analysis to describe in a consistent way alternative assumptions on economic growth, technological progress and social development. The SRES (Nakicenovic and Swart 2000) developed four major alternative storylines that lead to four different GHG concentration pathways. The emission scenarios were then used by GCM to predict future climate change. The storylines behind the SRES scenarios can be used to build scenarios of vulnerability to climate change. The IAM community is now developing a set of socio-economic and technological scenarios that would deliver the same emissions and concentration pathways of the RCPs (see item 1 above). The aim is to supply a set of alternative worlds that are compatible with a given climate change scenario. This multitude of scenarios is meant to span a wide range of assumptions that affect both mitigation and adaptation. For example, RCP 8.5 could emerge from a world with very high economic growth and high-energy efficiency as well as from a world with staggering, very energy intensive, economic development. Different regional economic patterns might conduce to the same global level of GHG concentrations. Mitigation would imply different challenges in the two worlds depicted above, even if the overall reduction of emissions is the same. Analogously, adaptation to climate change raises different challenges in the two worlds. The new scenario matrix architecture is not available yet at the time of publication. It is possible to follow the work progress from the Integrated Assessment Model Consortium website (www.globalchange.umd.edu/iamc/).

Efficient adaptation options can be estimated using many different methods. This toolkit presents methods available to study adaptation in many different sectors and also presents methods to study adaptations that involve more than one sector.

Figure 7. Intertemporal distribution of costs and benefits



Notes: A typical distribution of costs and benefits over time for a project of adaptation to climate change. The project requires a large investment and then annual maintenance costs. Until the project becomes operational, there may be no benefits from the project.

5.4 TIMING

Some investments in adaptation are annual in nature with annual cost and annual benefits. However, other adaptations involve investments in capital where the costs are spent up front and the benefits are distributed far into the future, as depicted in Figure 7. While the capital project is being constructed, costs will far exceed benefits. However, once it is in place, costs will fall and benefits will exceed annual costs. It is therefore important to understand how cost-benefit analysis weighs costs and benefits over time.

How does discounting affect the decision to build a dam now or later? Suppose that a dam would be needed in 2075 to avoid serious flooding from increased rainfall predicted in this period. Suppose that the damage from that flooding was US$ 15 million in 2075 and the cost of building the dam is just US$ 10 million. Ignoring discounting, the benefit exceeds the cost and the dam should be built by 2075. But should it be built now? At a five per cent interest rate, the present value of the flooding today is just US$ 500,000. It does not make sense to spend US$ 10 million today to eliminate a US$ 500,000 future problem. In contrast, as 2075 approaches and the present value of the flooding rises towards US$ 15 million, the US$ 10 million cost becomes more than justified. The discounting gets the decision maker to choose the right timing for the project.

The opportunity cost of investment funds (interest rate) may be even higher in least developed economies than in developed ones because their access to capital may be restricted. There may be many demands on scarce capital to finance education, public health, infrastructure, and other public goods. The scarcer is capital, the higher the implicit interest rate, and the more important it is to include the interest rate in making public capital decisions.

5.5 UNCERTAINTY

This section extends the cost-benefit analysis described earlier to account for uncertainty. Uncertainty can apply to either the cost or the benefit of projects but it is typically the benefits that are often the most uncertain. How should cost benefit analysis incorporate uncertainty?

For example, farmers often do not know how much fertilizer to apply because this year's rainfall is uncertain. From past observations, the farmer may know the probability that there will be a drought (p1), and the probability there will be ample rain (1-p1) (see Figure 4). They may know to choose A' in a wet year and A'' in a dry year (see Figure 6). But what should they do if all they know is the probability of each state?

If agents know the probability of random events and the outcomes in all cases, they can use standard tools for risk management to evaluate how to decide under uncertainty.

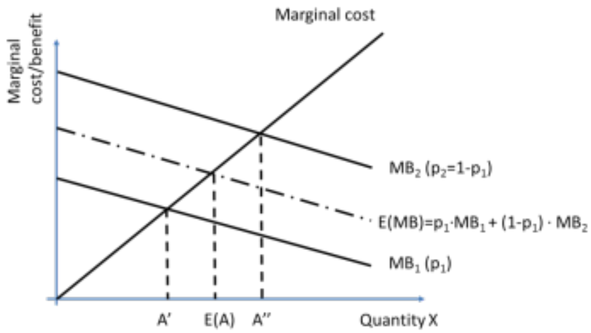
OPPORTUNITY COST AND TIME VALUE OF MONEY

Economic actors have limited funds to allocate and must choose investments that provide the highest return. For each investment what is the opportunity cost of those resources i.e. what is the next best thing one could do with the funds? If the opportunity cost is a project that provides higher returns we must re-think our investment portfolio.

Money has a time-value measured by the market rate of interest. Projects are evaluated every day all across the world in terms of the interest rate that they would generate. Projects that earn more than the market rate are funded. Projects that earn less than the market rate are not funded. Adaptation projects must compete in this market for funds. They therefore have to earn the market rate of interest to be funded.

Risk neutral agents should calculate the expected return from each decision across all the possible outcomes. For each level of fertilizer, they need to know what would happen in each of the different rainfall scenarios. They should then sum the outcomes weighting each outcome by the probability that it will occur. They should choose their fertilizer amount based on the expected outcome. Some years will be droughts and some years will have ample rain, but the level of fertilizer associated with the expected outcome will give them the highest long run income.

Figure 8: Cost benefit analysis under risk



Notes: cost-benefit analysis when marginal benefits (MB) are risky. The probabilities p1 and p2 indicate two possible states of nature under which the MB curve takes different shapes. The expected marginal benefit is equal to the probability-weighted average of the two MB curves. The optimal adaptation would be equal to E(A)=p1·A' + (1-p1) A''.

However, it is possible that the individual cannot survive a bad outcome that might be associated with the drought. If he chooses the expected outcome he may not live long enough to enjoy the long-term benefits. In such dire circumstances, the individual must weigh the bad outcomes more heavily. The person becomes risk averse. Instead of choosing E[A], the person may lean more towards choosing A' so that he can survive even in drought conditions. This leads to lower long run returns but it assures survival. The development literature is full of arguments concerning whether relatively poor rural farmers are risk-averse or risk neutral.

5.6 CLIMATE UNCERAINTY

Long-lived adaptation projects are inherently uncertain because future conditions are inherently uncertain. Even without climate change, long-lived projects face uncertain future prices and conditions. Climate change merely adds one more element to this list. Although scientists are confident the world will warm, there remains a lot of uncertainty concerning how much it will warm. Specifically, how much each local climate will warm remains uncertain, especially the further into the future one looks. Other dimensions of climate are perhaps even more uncertain. How will precipitation change? What will happen in each season? Will the variance of climate (weather changes) also change? What will happen to extreme events? Investments into long-lived projects that are sensitive to these phenomena must deal with these uncertainties.

Because adaptations are largely local, the climate that matters is the future local climate. However, despite the remarkable progress of climate science, predicting future local climate changes is still very uncertain. Many uncertainties are unresolved and will remain unclear for many years. Future climate change at local level is uncertain due to four main reasons:

1. Large political and technological factors may change over a long time period making the actual trajectory of GHG emissions uncertain. For example, growth rates of economies and the fraction of energy needed per unit GDP could change. How successful the international community will be to implement global GHG emissions mitigation is not known. These factors could lead to a wide range of future emission pathways. Each pathway would lead to very different concentrations of greenhouse gases over time. The more time that passes, the greater this uncertainty becomes. There are uncertainties concerning the relationship between GHG concentrations and global warming. We know with a high degree of

confidence that rising global concentrations of GHG in the atmosphere lead to an increase of global mean temperature and global precipitations. But exactly how much global temperature increase depends on global forces that accelerate versus dampen the effect of manmade greenhouse gases. Climate models differ assume very different temperature sensitivities (IPCC 2007).

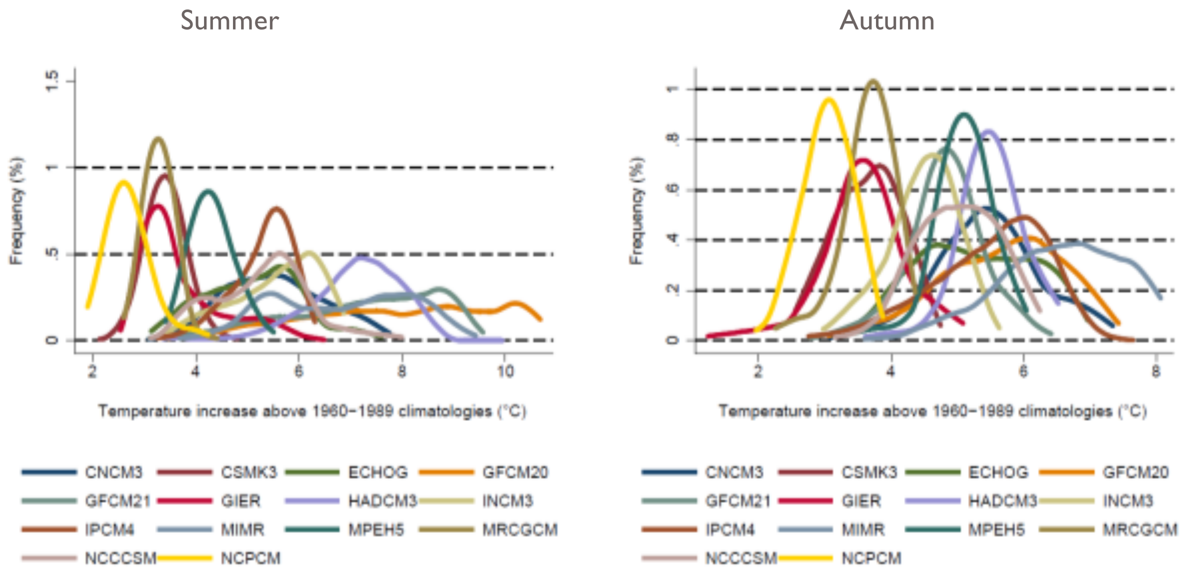
2. For every global temperature, climate models project a very different set of local temperatures. All the models agree that temperature will not change uniformly across the planet. But how local climate changes vary from one model to the next.[15] There is some agreement between models on climate trends in some regions of the world. However, there is also a large divergence among models on local climate changes. It is important to understand that climate is an intrinsically chaotic system with very complicated interactions between the atmosphere and the biosphere. Predictions at the global or continental scale have more precision because disturbances tend to offset each other at large scale. Predicting future climate change at the local scale is much more difficult because it depends on a lot of local detail that is not yet in the climate models. For example, the conformation of soil and vegetation considerably alter the microclimate. The shape of the landscape affects local climate. Given the large grid boxes in current models, such local detail is not yet included. The models cannot account for all these factors that affect climate at the local level. Even new generation earth-system models that integrate the atmosphere, the oceans and land are still dominated by large uncertainties (actually, higher complexity usually leads to higher uncertainty). Although new generations of models are expected to improve our understanding of future climate changes as new techniques are developed and new data becomes available, the learning process appears to be slow. Therefore there will be large uncertainties for still many years.

Figure 9 illustrates the degree of uncertainty that decision makers face when dealing with climate change scenarios. The figure illustrates the probability density function of mean seasonal warming in United States counties during the period 2080-2099 with respect to the 1960-1989 climatology, predicted by 14 GCMs for the Fourth Assessment Report of the IPCC, using the A2 scenario of the SRES. The Figure shows that all models expect that climate will be warmer in the United States but there are large differences among the scenarios. In some cases warming is expected to be modest (e.g. NCPCM), in others extreme (e.g. HadCM3 and GFCM20). The same variance across model is found for different regions, seasons and years.

The literature has often resolved this uncertainty by assuming that each scenario has the same probability to occur. Climatologists refer to this as "model democracy" (Knutti 2010). This is in fact equivalent to assuming that each GCM has the same chance of generating the "true" future climate change scenario. One can average across the climate scenarios to find an expected outcome. However, the impact response of many systems is not linear. So the expected impact across the different models is not the same as the impact of the expected climate. Further, none of the climate models predict the expected climate across all of them. The expected climate may be an outcome (a mixture of scenarios) that is not even possible. One is consequently forced to examine multiple climate scenarios.

[15] HadGEM1, the most advanced GCM of the British Met Office, has a surface resolution of about 208 km x 139 km at the Equator, which becomes equal to 120 km x 139 km at 55 degrees of latitude. The older generation of models has a resolution that varies from 250 km x 250 km to 600 km x 600km.

Figure 9: Distribution of warming across United States counties in Summer and Autumn



Notes: Mean seasonal temperature increase in 2080-2099 with respect to 1960-1989 climatologies. SRES scenario A2 for the Fourth Assessment Report of the IPCC. Each probability density function depicts the probability that one county in the United States has the temperature change measured on the horizontal axis. Source: reproduced from Athanassoglou and Massetti (2012), elaboration based on data available at the IPCC data distribution centre http://www.ipcc-data.org/ .

This large uncertainty dampens the attractiveness of anticipatory adaptations that are made to get ready for future climate change. Once the climate changes, it is no longer uncertain (at least for the moment). Short-term reactive adaptations, made after the climate changes, face much less climate uncertainty than anticipatory actions. It is consequently likely that people will engage in reactive adaptations. How much anticipatory adaptation will occur, in contrast, will depend on how uncertain future climate predictions remain. Uncertainty about future socio-economic pathways.

MODEL DEMOCRACY

It is not obvious which climate model to pick. Scientists have not been able to assign weights to the outcomes of different models. From a policy perspective, the wisest choice may be to assume all climate model scenarios are equally plausible. By examining a range of outcomes (models), the adaptation analysis can capture the inherent uncertainty in climate modeling.

Future socio-economic economic scenarios are needed to estimate the vulnerability of individuals to climate change impacts. For this reason uncertainties about future alternative scenarios affect cost-benefit analysis. Analysts have the option of generating their own socio-economic scenarios or may use scenarios developed by the IAM community. There is an abundance of studies examining future socio-economic pathways. Project analysts should be aware of how these factors may change in their region. It is not possible to attribute exact probabilities to different socio-economic pathways and to climate scenarios. The uncertainty surrounding the probabilities adds to the overall uncertainty surrounding outcomes.

5.7 METHODS TO DEAL WITH UNCERTAINTY

One flaw in many past studies is that they did not model the uncertainty at all. Some studies examined the consequences of only a single model. Other studies looked at many climate outcomes but chose the average outcome across them. Such approaches provide a false sense of certainty since only one plausible outcome is examined. For long-range projects, it is important to study the forecasts of more than one model and more than one socioeconomic scenario.

Embracing the full range of climate and socio-economic scenarios requires a method to deal with uncertainty. There are two broad classes of methods that practitioners use to incorporate uncertainty in adaptation projects in a transparent way:

1. Expert elicitation. In some cases probabilities of random outcomes may be difficult to assess using data analysis but experts may have a good understanding of how likely the events are. Expert judgement can be used to assess how "realistic" uncertain scenarios are. Expert elicitation is a way to systematically formalize experts' judgement in terms of probabilities. The method has been used to assess high-consequences low-probability events such as nuclear disasters and seismic hazard. In 1978, the National Defence University in the United States surveyed expert opinions on climate change scenarios until the year 2000 (National Defence University 1978). The Environmental Protection Agency (EPA) of the United States has used the method to assess uncertain environmental outcomes (EPA 2009).
2. Theory of robust decision-making. Economists have traditionally worked under the assumption that probabilities of random events are known. The theory of decision making under risk is well developed and widely used. Only recently, new theory developments have embraced the more complex task of assessing decisions when probabilities are not known (for a review see Ghirardato 2010). If individuals are highly risk averse, one solution is to turn to maximise expected utility model (Gilboa and Schmeidler 1989). The model examines the worst-case scenario and makes decisions based solely on that outcome. The problem with this approach is that it focuses solely on the worst case and completely ignores all other possibilities. Decision makers with vivid imaginations can trap themselves into making decisions solely on their worst nightmare and following an adaptation policy designed for a world with little resemblance to the real world. Models that require less stringent assumptions on risk preferences exist, but it is still unclear how they could be applied to evaluate adaptation projects (Klibanoff, Marinacci, and Mukerji 2005; Athanassoglou and Massetti 2012).

DEALING WITH UNCERTAINTY

Given the large uncertainty in climate predictions and forecasting future conditions:

1. Examine a set of model outcomes.
2. Examine a range of plausible socioeconomic scenarios
3. Predict outcomes for each scenario.
4. .Make the best decision possible under the inherent uncertainty.

SUMMARY OF KEY MESSAGES

- **Efficient adaptation requires that each project maximize net benefits- the difference between benefit and cost. This implies that:**
  - **Only projects for which the benefit is greater than the cost should be financed;**
  - **The benefit of each action/adaptation within a project should exceed its cost**
- **Public agencies can provide public adaptations by either doing the adaptations themselves or by providing incentives (for example subsidies) for private actors to generate the efficient level of public goods**
- **Estimate all the costs of a project not just budget items.**
- **Assessing the benefit of an adaptation project requires:**
  - **A set of climate change scenarios;**
  - **A set of socioeconomic scenarios**
  - **Predicted environmental consequences over time;**
  - **A valuation of those consequences over time**
  - **Calculation of the present value of the stream of annual benefits**
  - **Comparison of the cost against the present value of benefits of the project. .**
- **The benefits of all long-lived projects will invariably be uncertain. Public choices of projects can often use the expected value of those benefits. In some circumstances, decisions should be risk-averse implying avoiding more risky projects. There are methods to deal with uncertainty and long-term investment planning, but investing in adaptation to long-term climate change remains a very risky business (i.e. returns are highly uncertain).**

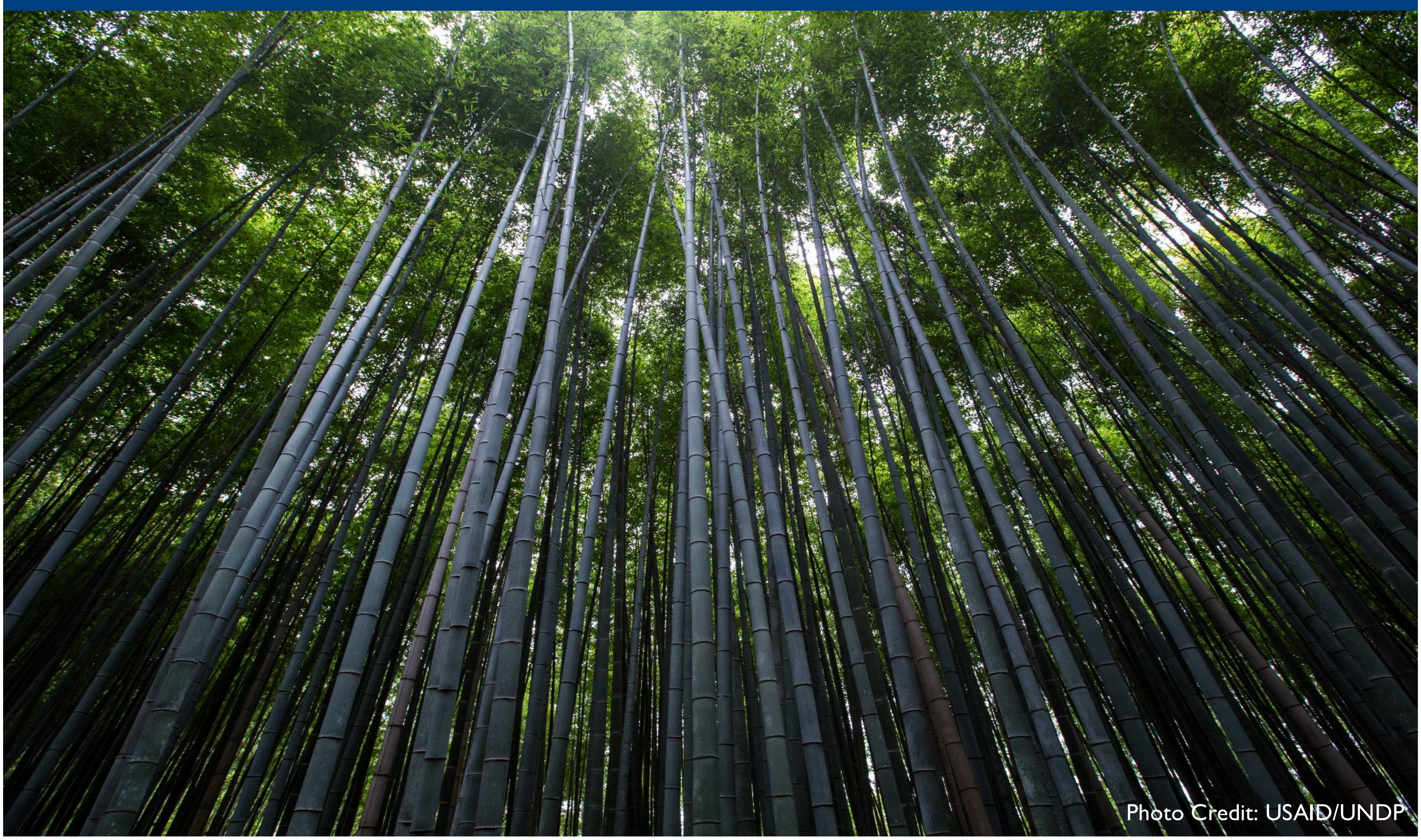


Photo Credit: USAID/UNDP

ANNEXES

MACROECONOMIC ASSESSMENT

This toolkit has taken a sectoral perspective to climate change impacts because the nature of adaptation varies a great deal across sectors. There are different climate threats to agriculture, forestry, health, coasts, water systems, and other climate sensitive sectors. More importantly, how one addresses these threats is unique to each sector. In some cases, impacts cross sector boundaries and affect related sectors simultaneously. A drought will directly affect farms through reduced precipitation but it simultaneously may reduce runoff, which will affect irrigation water to the farms. Sea level rise poses risks to coastal communities but these risks can be amplified if coastal storms also intensify. These connections between sectors need to be examined as they may change the effectiveness of different adaptation strategies. Nonetheless, sectoral models are still the best way to address these issues because they contain the needed detail to identify optimal strategies.

However, one phenomenon that sectoral models can miss concerns large-scale aggregate changes to the economy that alter wage rates, interest rate, and possibly land rents. Changes to these fundamental prices can cause important changes throughout the economy, even in sectors that are not directly sensitive to climate. Sectoral models are not designed to capture these "general equilibrium" effects. In order to measure general equilibrium effects, one must turn to macroeconomic models that capture economy wide consequences of large changes in economic systems. These models capture how all economic activities are interconnected in a complex system. As the system is disturbed, the entire system reacts. Distortions in the system from government policies, taxes, externalities, and market failures can be exacerbated or sometimes relieved by these changes. General equilibrium models are designed to measure these systemic effects. Of course, there are drawbacks to general equilibrium models as well. They cannot capture the detail of the sectoral models. They do not have any mechanisms to measure climate effects. They are often poorly calibrated for developing countries where the bulk of the climate damages are likely to occur. They often cannot capture the serious market imperfections in many developing countries. So it is not wise to rely solely on general equilibrium models to guide adaptation. They simply do not contain sufficient detail to provide concrete advice.

However, if countries are concerned that they may face widespread changes in their economies based on sectoral studies, they may want to consult a general equilibrium model to understand what impacts these changes may have on the entire economy. For example, if studies suggest that vast agricultural areas might have to be abandoned in the future, a large fraction of the workforce may need to find new employment in nonfarm activities. The country may want to seriously consider alternative development plans that draw workers into new sectors of the economy that are not sensitive to climate. This could include internal migration strategies of drawing workers to high productivity urban areas. Island nations may want to consider plans to develop certain islands more than others as part of a long-term strategy. The macroeconomic modelling makes clear the strong link between development and climate adaptation over the long run.

Two broad types of models capture economy wide impacts. Computable general equilibrium models (CGE) with some geographic and sectoral detail of the economy are suited to study the inter-sectoral and international implications of climate change impacts and adaptation policies. Growth models (dynamic models) are used to study long-term implications of changing investment and thus productive capital over time. The growth models can provide useful information on the optimal timing of adaptation policies and the long-term benefits of reducing climate change impacts. The key with both sets of models is that the parameters of the models be carefully calibrated with available data.

COMPUTABLE GENERAL EQUILIBRIUM MODELS

Computable general equilibrium models (CGE) study the equilibrium between supply and demand across key integrating markets in the economy; namely labour and capital. Through effects on wages and interest rates, impacts in one sector of the economy can affect other sectors. Partial-equilibrium models tend to focus on only one sector at a time. General equilibrium model examine all sectors together. For example, the global timber models are partial equilibrium models of just the timber sector. They do not capture changes in prices in agriculture, water, or industry. They assume that wages and interest rates are fixed. General equilibrium models examine equilibriums across all sectors simultaneously and capture all price changes across every market. They illustrate how the impact in one sector propagates through the economy. For example, by increasing the amount of land in forestry, a general equilibrium model would capture the increased scarcity of agricultural land and the rising prices of food. Similarly, a general equilibrium model would capture the effects on private industry if vast capital funds were diverted to adaptation activities.

The greater is the impact of climate change in one sector and the larger the share of GDP from that sector, the larger is the indirect impact of climate change on other sectors. For example, the impact on agriculture in least developed countries might have large macroeconomic implications because it can be the very largest sector in some countries. Large changes in agriculture could then lead to changes in wages and land, which would affect how other sectors behave. Some models are also designed to capture trade effects. If climate change reduces a country's exports, the country will either have to increase other exports or reduce imports. This spreads impacts to other countries and other sectors. For example, if Europe chooses to increase biofuels to reduce their GHG emissions, countries that grow biofuels may increase their production and export more to Europe. They will in turn buy new imports that they could not previously afford. Further, to grow the extra biofuel, the exporting countries may well remove some of their forestland to increase their cropland. Macro models are well suited to understand these systemic effects.

GENERAL EQUILIBRIUM MODELS

All sectors of an economy are connected to each other. Large changes in one sector can affect the prices and quantities in other sectors. General equilibrium models are often poorly suited to identify damages or adaptations in any one sector because they lack detailed sectoral information. However, if it is clear that climate change will cause large sectoral changes in important components of the economy, general equilibrium models can predict the consequences these changes will have throughout the economy.

Berrittella et al. (2006), Bosello, Roson, and Tol (2006), Bosello, Roson, and Tol (2007) are examples of studies that assess the macroeconomic impact of climate change using CGE models. Each work studies how impacts in one sector (tourism, health and sea-level rise, respectively) affect the macro economy, with and without explicit adaptation policies. They use a macroeconomic model based on the Global Trade Analysis Project model (GTAP), a global trade model of the world economy (www.gtap.org; Hertel 1999).

For example, Bosello, Roson, and Tol (2007) start by developing a baseline scenario for the world economy in 2050. They use projections from other models or assumptions about economic growth, population, resources availability and other relevant variables. By definition, the baseline scenario has no climate change. They then create a scenario in which sea-level rise reduces coastal land. They do not include explicit protections like sea walls, but they let markets work to re-allocate land between sectors. For example, agricultural land lost along the coastline can be replaced by agricultural land from the interior.

Some economists also use IAMs to provide an answer to the optimal balance between adaptation and mitigation. They find that it would be optimal to invest more in mitigation than in adaptation in the first half of the century because there is little climate change to adapt to (de Bruin, Dellink, and Agrawala 2009; Bosello, Carraro, and De Cian 2010; Carraro and Massetti 2011). However, they also find that adaptation should grow dramatically in the second half of the century as countries are forced to adapt to large changes in climate.

The merits of specific macroeconomic models depend a great deal on their characteristics. Some of the models are designed to capture a specific sector in great detail and other sectors much more abstractly. Consequently, the types of questions models can answer often vary depending on how the model is constructed. As with all models, the accuracy of macroeconomic models depends upon how well they are calibrated. Models that have carefully obtained the existing relationships between one sector and another will give more accurate results. Models which use arbitrary or biased assumptions will get arbitrary or biased results.

If macroeconomic models evaluate entire economies, why bother analysing partial equilibrium models that study only one sector? The limitation of macroeconomic models is that they require enormous amounts of information. One has to know about every sector in the economy, how it responds to climate change, and how each sector interacts with all the other sectors. We simply do not know enough about every sector to build detailed models about them all. Macroeconomic models consequently tend to rely on crude models of each sector in order to model every one. There is a trade-off between capturing broad knowledge about the entire economy versus capturing specific knowledge about each sector. If climate change or adaptation has a large enough signal, macroeconomic models can show how that signal permeates through the economy. But partial equilibrium models are often much better at discerning what impact climate change would have and what adaptation is most appropriate in a specific sector. Macroeconomic models may provide insight into the big picture but good public policy often depends on the details.

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