METHODS FOR ECONOMIC ANALYSIS OF CLIMATE CHANGE ADAPTATION INTERVENTIONS

JANUARY 2013

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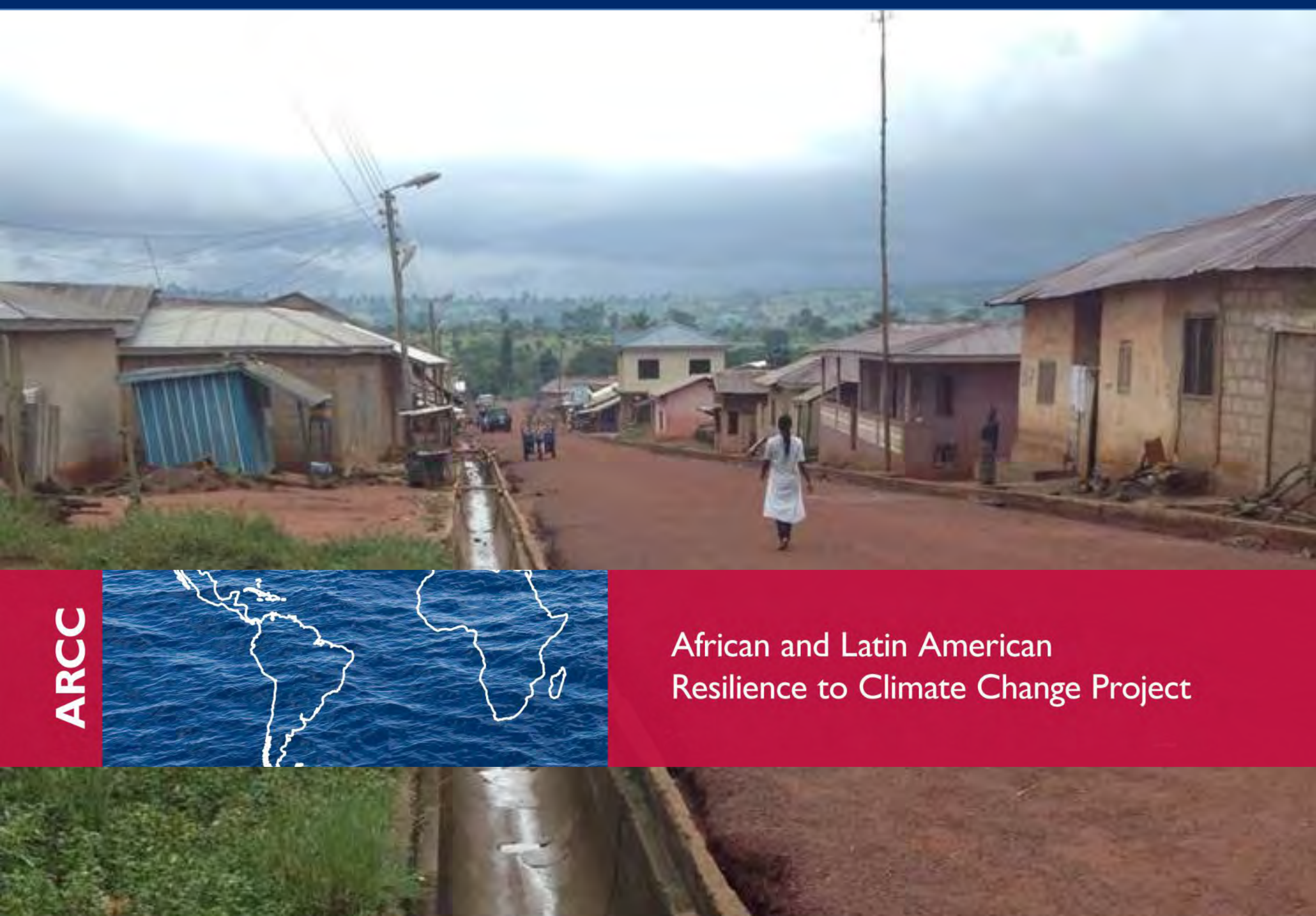

ARCC

African and Latin American Resilience to Climate Change Project

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AFRICAN AND LATIN AMERICAN RESILIENCE TO CLIMATE CHANGE (ARCC)

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ACRONYMS AND ABBREVIATIONS

CBA	Cost-Benefit Analysis
CBNRM	Community-Based Natural Resource Management
CEA	Cost Effectiveness Analysis
CGE	Computable General Equilibrium model
DALY	Disability Adjusted Life Year
DEM	Digital Elevation Model
DIVA	Dynamic Interactive Vulnerability Assessment
DRR	Disaster Risk Reduction
DSSAT	Decision Support System for Agrotechnology Transfer
EVRI	Environmental Valuation Research Inventory
FAO	United Nations Food and Agriculture Organisation
GCM	Global Circulation Model
GHG	Greenhouse Gas
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
ISET	Institute for Social and Environmental Transition
SRES	Special Report on Emissions Scenarios
UKCIP	United Kingdom Climate Impacts Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
WBEACC	World Bank Economics of Adaptation to Climate Change
WHO	World Health Organization

EXECUTIVE SUMMARY

This paper describes best practices for how and when to carry out economic evaluations of proposed climate change adaptation activities, which focus primarily on cost-benefit analysis (CBA). It is organized around the steps in estimating first the benefits of adaptation and then the costs involved. Because the benefits of adaptation are generally expressed in terms of prevented harm, we begin with the complex steps involved in estimating the harm caused by climate change, and then discuss how these estimates are integrated into a CBA and compared with costs.

The paper is organized into eight sections:

Section 1.0 introduces the basic concepts of CBA. It presents some of the concerns of the use of this tool; for example, how the availability of resources for the analysis will determine how it will be carried out. It also touches on some of the limitations of economic analysis and CBA, including the difficulty in quantifying and monetizing the benefits of some soft adaptations, the ethical issues involved in monetizing health impacts, and the extent to which one can use CBA to address equity issues in choosing adaptation strategies.

Section 2.0 provides a framework for thinking about the baseline in economic analysis of adaptation activities. The baseline is the counterfactual, or what would happen in the future if there were no climate change. This section explains the need to consider the impacts of climate change, the impacts of demographic or economic shifts that will occur by the time the climate has changed, and the combination of the two in order to arrive at a baseline that shows the situation in the absence of adaptation.

Section 3.0 considers how analysts identify the local impacts of climate change. This is the first step in estimating the harm caused by climate change, and thus the benefits brought about by adaptation interventions that prevent that harm. While assessments of harm will generally be used as an input to a CBA rather than carried out as part of the CBA, it is useful to have some understanding of how analysts estimate local impact.

Section 4.0 discusses how to determine who and what will be exposed to climate change hazards at the local level. It sets out generic steps to identify the current situation in the location and sector of interest; the expected change in the climate (output of the analysis described in Section 3); the expected social and economic changes in the area; and then the combination of the preceding two factors to identify and quantify the impacts of exposure to climate change. The use of these steps is then described for four areas of major climate change impact: 1) coastal flooding, 2) agriculture and food security, 3) health, and 4) biodiversity and ecosystems. A wide range of tools may be used to carry out this analysis; the choice among tools will be based on available data and the time and resources available to carry out the CBA.

Section 5.0 presents tools for estimating the monetary value of harm caused by exposure to climate change hazards. The same tools — and usually the same values — will also be used to put a monetary value on the benefits of adaptation; so this is the third step in estimating the benefits brought about by adaptation. These tools are available to assess the loss of income flows; loss of non-marketed goods and services that will be affected by climate change; and changes to the value of productive assets, such as land or forests. The tools for monetizing health impacts are discussed separately because of the ethical issues involved in putting a value on a human life. Section 5.0 also considers the practice of benefit transfer and the models used to address multiplier effects.

Section 6.0 explicitly considers issues related to quantifying and putting a monetary value on direct and indirect benefits and costs of adaptation activities. It considers hard and soft adaptations separately, because the challenges of estimating the direct benefits of soft adaptations are quite different from those for hard adaptations. This section also considers how to handle a portfolio of adaptations, rather than a single one on its own, and the distinctions between CBA for stand-alone adaptation activities and adaptation integrated into other projects.

Section 7.0 discusses different ways to use the results of the CBA in decision making. One important issue is understanding how CBA can be adjusted to handle climate risk. A second question discussed here is the limitations of using CBA to address equity concerns. The third focuses on the limits of economic approaches in choosing among adaptation activities, with a brief description of related non-economic analytical techniques that can be used when economic analysis is unfeasible or inappropriate.

Section 8.0 concludes the paper with recommendations for how CBA may be integrated into the adaptation work of development agencies.

1.0 INTRODUCTION

This paper describes best practices for how and when to carry out economic evaluations of proposed climate change adaptation activities, focusing primarily on CBA. Within the overall framework of CBA, many different analytical methods and tools can be used to assess the value of specific impacts of climate change, specific benefits offered by effective adaptation, or specific costs of implementing those adaptation strategies. These methods and tools span much of the spectrum of economic and financial analysis and modeling, but are all inputs into a unifying framework provided by CBA.

1.1 ABOUT COST-BENEFIT ANALYSIS

The basic concept of CBA is simple. An activity is proposed to address a problem, which can be anything from the construction of a new road, to the introduction of new seed varieties, to the widespread dissemination of a preventive health tool. The CBA assesses the total costs of implementing the activity and the total benefits, and then compares them. If the benefits exceed the costs, then the activity is considered to have "passed" the test.

CBAs within the realm of climate change adaptations take the same broad approach:

1. Climate change will have an impact on lives and livelihoods.[1] First we need to measure that impact. What will the specific impacts be? Who will be affected? And how can we place a value on that impact in monetary terms?
2. A proposed adaptation activity (or portfolio of activities) reduces negative impacts. We need to assess how much each activity will reduce harm in both physical and monetary terms.
3. The activity (or portfolio of activities) will cost something to implement. We need estimates of the cost of adaptation activities.

Again, if the benefits exceed the costs — or if the benefit to cost ratio is greater than one — the activity may be considered worthwhile from an economic perspective. If we were to choose among a number of activities purely based on economic criteria, this approach could lead us to rank them by benefit-cost ratio and to begin implementing them in order of their place on the list.

In practice, of course, the devil is in the details. There are different ways to estimate the costs and benefits of a proposed activity, ranging from the very simple to very complex, each of which has its own embedded assumptions. In many cases, a more complex analysis may give more reliable results; however, they also require more time, more skill, and more reliable data. Complex analyses typically

[1] In climate change and adaptation discussions, the word "cost" is often used to refer to two different things. The negative impacts on people because the climate has changed are referred to as the cost of climate change. In response, people invest in activities to protect themselves or increase their resilience; expenditures on those activities are referred to as the cost of adaptation. To avoid confusion, wherever possible, this paper uses the word "impact" or "harm" to refer to the negative impacts of climate change, while "cost" is used only to refer to the expenditures needed to prevent that harm. In some cases this does not make sense; it is important, therefore, to bear in mind the distinction so as not to confuse the two different sets of costs being discussed.

cost more to carry out, which means that the cost of a CBA could exceed the cost of the adaptation activity itself.

The most significant difference between CBA in general and CBA for climate change adaptation has to do with risk and uncertainty. Unlike CBAs carried out in the past, when changes were relatively predictable and could be incorporated into the analysis, CBAs now must factor in how climate change will affect baseline conditions. For some development challenges, that might require CBA to evaluate appropriate interventions; climate change may not be particularly important, so this will not be a major constraint. However, for activities related to agriculture, infrastructure, urban development, coastal management, and other geographic and sectoral areas, climate change is likely to have significant impacts that must be integrated into the design of development interventions and into CBAs of potential activities. For activities whose core purpose is to build resilience and to adapt to climate change, of course, the nature of those impacts will be of primary importance to the design both of the activity and of the CBA. Even in cases where we know that climate change will impact a sector, predicting the magnitude and frequency of impacts is inherently filled with uncertainty. Factoring this uncertainty into CBA and into project design is one of the major challenges of climate change adaptation.

1.2 ISSUES IN USING CBA FOR ADAPTATION

In considering how CBA can be carried out for adaptation activities, this paper considers several dimensions of the applicability of the different analysis tools:

- For the most part, the methods discussed are suitable for both hard (infrastructure-based) and soft (policy, governance, and capacity building) adaptations. However, there will be differences in how costs and benefits are estimated for each. Some soft adaptations, particularly those oriented toward capacity building for adaptation work, do not lend themselves to CBA, as discussed in Section 6.0 on integrating costs and benefits into the analysis.
- CBA can be used for both dedicated discrete adaptation projects and activities that are integrated into other projects. However, it is likely to be most useful for discrete projects. At the extreme, when adaptation is fully integrated into a project — for example, when a new road is sited so that it will not be vulnerable to expected increases in flooding — it may simply not make sense to analyze the costs and benefits of the adaptation component of the project separately from the rest of the project. If adaptation work is made up of distinct activities within a project in some other sector, then those activities could be analyzed separately from the project as a whole, which follow essentially the same approaches as those used for discrete adaptation activities. The limitations of CBA for integrated adaptation are discussed in Section 6.0 on identifying the benefits and costs of adaptation.
- CBA can be used for stand-alone adaptation projects or for a portfolio of projects. The issues involved in carrying out a CBA for a portfolio are discussed in Section 6.0.
- Not all adaptation work will be managed by the public sector or international donors; individuals will autonomously adapt to some climate change on their own. To give an example: when confronted with a flood, people will move to higher ground; they will not sit in place and drown for lack of a government project to help them head uphill. Much autonomous adaptation will, of course, be much more subtle than this example. The question arises, therefore, of where it fits in our CBA. The answer, for the most part, is that it doesn't fit. Public agencies carry out CBA to decide how to use their own funds; they do not analyze private sector decisions such as autonomous adaptation. The place of autonomous adaptation does arise in analyses of the total social cost of all adaptation to climate change. However, this paper is focused on project assessment, not on assessing the total cost of adaptation to the economy.

- All CBA depends on making assumptions or developing hypotheses, whether they are about how population will grow, how the climate will actually change, how people will respond to these changes, how ecosystems will respond to these changes, or any of dozens of other issues. In some cases, we have scientific information about how one change will bring about others; in many cases, we must suggest hypotheses or make assumptions about these impacts. This is an unavoidable element of any economic analysis; it involves predictions based on partial knowledge. As we evaluate any economic analysis, we must understand the assumptions that underlie it so that we can determine whether the analysis is valid.

1.3 LIMITS OF ECONOMIC ANALYSIS

This paper focuses on economic analysis of harm caused by climate change and of the adaptation interventions that can prevent that harm; it does not systematically address non-economic criteria for choosing among adaptation strategies. This perspective is distinctly limited. Adaptation activities will be chosen based on many considerations in addition to economic ones: community values, social structure, politics, and availability of funding, whether the proposed activities benefit the rich or the poor, and so on. Moreover, both climate change and adaptation activities may have direct impacts that cannot acceptably be measured in monetary terms, notably those related to human health or biodiversity. Some non-marketed impacts — such as those on services of the natural environment that could be replaced through the economy — can be valued in monetary terms, but putting a value on the loss of human life or unique ecosystems is often considered to be highly problematic and is best avoided.

These limitations of economic assessment are widely recognized. Many of the major studies on economic assessment of adaptation — the World Bank Economics of Adaptation to Climate Change (World Bank, 2010b), the work of the Economic Costs of Adaptation Working Group (ECAWG, 2009), and the "Risk to Resilience" work of the Institute for Social and Environmental Transition (ISET) — discuss the importance of placing economic results within a broader decision-making context. That context would factor in important social, cultural, ethical, and other considerations along with benefit-cost ratios. It would also be able to include more practical considerations, such as the ease of implementation of different adaptation tools, or the extent to which they depend on highly skilled outside experts whose work would be incomprehensible to the community concerned.

Other analytical methods — such as multi-criteria assessment (the subject of another study in this series) and qualitative CBA (discussed in Section 7.0 of this paper) — can help put economic and non-economic aspects of climate change and adaptation into a rigorous framework that facilitates comparisons. Even these tools, however, may not always be sufficient to provide a clear basis for decision making. In some situations, both CBA and non-economic analytical tools may be more useful as a way to structure community discussion of the trade-offs between adaptation and other development priorities as well as among adaptation options, as opposed to acting as a rule for actually making decisions. Particularly in cases where small communities decide what works best for them, these analytical tools may be most useful as a framework for thinking about preferences and values, and balancing economic considerations against other objectives that cannot be expressed in monetary terms.

1.4 CRITERIA FOR REVIEWING ANALYTICAL METHODS

The question of the suitability of analytical methods has two dimensions. The broader one pertains to whether economic assessment is the right tool for evaluating our plans at all. This dimension has already been discussed briefly and is also considered in Section 7.0 on how to use CBA results in decision making.

The second dimension is narrower and pertains to decisions on how to conduct the CBA. Key elements of the CBA include projecting the impacts of climate change in the future, putting monetary values on the harm it causes, and identifying the benefits and costs of adaptation activities. The CBA can be carried out in many different ways. Various factors go into determining which analytical tools are suitable or how they should be used:

- Some analytical or costing methods are specific to one sector, such as agriculture or health.
- The practical requirements for implementing analytical tools vary substantially. There are several important components to these requirements: data needs, skill level of the analysts, time to carry out the analysis, financial resources for the analysis, and ease with which the process can be grasped by decision makers. Projections and cost analyses can be done using sophisticated tools that are data-, skill- , and time-intensive, or by simpler methods whose results are often (though not always) less accurate, but that are much faster, cheaper, and less data-demanding. The resources available to carry out the analysis will be an important determinant of the methods used.
- Some issues are more difficult to address with rigorous models than others. Engineering solutions and other hard adaptation projects lend themselves readily to rigorous quantitative analysis, as do insurance schemes that redistribute the costs of climate change rather than actually reduce them. In contrast, many soft adaptations are less easily modeled. Activities such as building databases, decision support systems, and the skills to work with them will contribute to many adaptation activities, but it is inherently difficult to identify and put a monetary value on that contribution.
- Incorporating equity considerations into the analysis is important in many contexts. Typically this is not possible with CBA, because the method and resulting decision criteria involve summing the total benefits and total costs without regard to who experiences them. In some cases, it could be possible to disaggregate the analysis by groups in order to determine who pays and who receives the benefits, but this is not usually the case. This issue is discussed further in considering some of the analytical methods, and in Section 7.0.
- The ability to carry out sensitivity analyses is also useful in many contexts. A "sensitivity analysis" is one in which it is possible to modify some of the assumptions underlying a calculation or a projection, and to quickly see how the outcome changes as a result. Sensitivity analyses are also useful in studying the impact of activities we are considering, because they can let us easily determine how a change in our project design or in the inputs to our project will change its effectiveness. Not all analytical frameworks lend themselves to sensitivity analyses, but the option to use this approach is discussed wherever it is feasible.
- Some methods are better suited to participatory, community-based processes than others. Where community participation is particularly important, this may argue for use of less rigorous economic analysis tools, or in some case for not attempting to quantify economic impacts at all.

1.5 STRUCTURE OF THIS REPORT

This report begins by providing context for the analysis of adaptation options. Their benefits, a key part of any CBA, take the form of preventing the harm that climate change would cause in their absence. Therefore to carry out a CBA, we must first estimate (in physical and monetary terms) the harm caused by climate change. Then we must estimate how much of that harm will be prevented by a given adaptation activity. The monetary value of the prevented harm is the benefit of the adaptation activity. We compare that with the cost of implementing the adaptation activity in order to get a cost-benefit comparison. Consequently, Sections 2.0 to Section 8.0 of this report read as follows:

- Section 2.0 provides a framework for thinking about the baseline in economic analysis of adaptation activities. The baseline is the counterfactual, meaning what would happen in the future if there were no climate change.
- Section 3.0 considers how analysts identify the local impacts of climate change. This is the first step in estimating the harm caused by climate change, and thus the benefits brought about by adaptations that prevent that harm. While identification of local impacts of climate change will generally be taken as an input rather than carried out as part of the CBA, it is useful to have some understanding of how the identification of local impacts of climate change is addressed.
- Section 4.0 discusses how to determine who and what will be exposed to climate change hazards at the local level. This is the second step in estimating the harm caused by climate change and thus the benefits of adaptation.
- Section 5.0 presents tools for estimating the monetary value of the harm caused by exposure to climate change hazards. The same tools — and usually the same values — will also be used to put a monetary value on the benefits of adaptation, so this is the third step in estimating the benefits brought about by adaptation.
- Section 6.0 explicitly considers issues related to quantifying and putting a monetary value on direct and indirect benefits and costs of adaptation activities.
- Section 7.0 discusses different ways to use the results of the CBA in decision making, focusing in particular on the limits of economic approaches in choosing among adaptation activities.
- Section 8.0 concludes the paper with recommendations for how CBA may be integrated into the adaptation work of development agencies.

2.0 FRAMEWORK FOR ECONOMIC ANALYSIS: WHAT IS THE BASELINE?

In order to begin thinking about CBA, we need to be clear about what we are measuring and what we are comparing. Table 1 helps to clarify some of the different concepts. It highlights the differences between the current situation and the future with respect to two major issues: changes in the climate, and changes in "everything else," which for the most part refer to demography (population) and economy. The first column in the table refers to the present climate, while the second refers to the future climate. The first row refers to today's population and economy, while the second row refers to a time in the future when population will have grown. Population distribution will probably have shifted with migration and urbanization, the economy may have grown, and the economic structure may have changed. Other things in the "everything else" category may also be different down the road; for example, culture and values may evolve and the political system may change. Where these examples are important and predictable, specific analyses should include them as well.

TABLE 1. CAUSES OF PROJECTED CHANGE

Categories of Change	Current Climate Variability and Change	Climate Change in the Future
Current Social and Economic Context	This cell represents the current situation: today's social and economic contexts and the ways in which weather events affect them. Governments and citizens address these challenges routinely. Those in the field of disaster risk reduction (DRR) address the impacts of extreme weather events and have done so since before climate change became a concern. If capacity (investments, resources, skills, etc.) is insufficient to address today's weather disasters, this gap is referred to as the development deficit or the adaptation deficit.	Future needs will differ from current ones in part because of expected changes in climate.
Future Social and Economic Context	Even without climate change, population growth and economic change would lead to changes in development needs.	Projections of future needs will have to factor in both climate change and social and economic growth.

Table 1 provides a conceptual picture of the two categories of change that will occur over time: change in climate trends and change in demographic and social context. Both kinds of change will occur at the same time, but to project where we will be at some date in the future, we must consider each separately, and then combine their impacts to track the shift from today (in the light-shaded cell) to the future (in the dark-shaded cell). In practice, of course, the world will only actually find itself in one of the two colored cells; it won't experience one category of change without the other (the scenarios depicted in the white cells). For analytical purposes, however, the distinction is important because we must model the two kinds of change separately in order to estimate the impacts (physical or monetary) of future changes in climate, and thus the benefits of adaptation.

In many developing countries, there is a significant gap between how today's climate variability[2] is being addressed and how it might optimally be addressed. This is given the technical name of the "development gap" or the "adaptation gap;" but, in fact, it is no more than the difference between the way things are now being done, and the way they could be done if the country did not face all the challenges that come with poverty and underdevelopment. Thus, for example, farmers with relatively little knowledge and no investment capital will have few resources to respond to ordinary climate variability; but if agricultural development projects were highly effective, they would have more knowledge about good practices and would have enough savings that they could afford to take the risk of trying out new technologies. This "development gap" falls within the light-shaded cell of Table 1.

In studies that aim to estimate the global monetary harm caused by climate change and the total cost of adapting to it, there is some difference of opinion as to whether the costs of responding to this gap should be included. Some analysts, concerned with the need to plan now for an uncertain future, do not include the adaptation or development gap in their calculations. Instead, they focus only on how climate change will make the current situation even worse. This is true of the World Bank's national and global estimates of the costs of climate change (World Bank, 2010b). Others, more concerned about the total cost of managing or adapting to disaster risk (both current and future) must necessarily compare those costs with the combination of the current harm (the development gap) and the future harm from climate-related disasters. Such is the case of the work of the Economics of Climate Adaptation Working Group (ECAWG, 2009). While either approach is acceptable, they give quite different results, as estimates that omit the development or adaptation gap will be lower than those that include it.

Many adaptation activities do not focus on putting a monetary value on the global or even national harm caused by climate change, and this value may not be a key element in the economic assessment of a specific adaptation activity. However, the identification and valuation of the different kinds of harm caused by climate change will be an input into the identification of a portfolio of possible adaptation activities. In order to design and then choose among possible activities, we need to know where climate change impacts occur and how important each is according to some unit of measurement (monetary or otherwise), so that support can go to resolving the most serious problems rather than relatively minor ones.

Table 1 helps identify the different analyses that will be part of any CBA:

- The light-shaded cell pertains to the total harm now caused by climate variability. Analysis of the components of this harm, and of historic trends insofar as data are available, will provide a starting point for considering change over time. This will provide a baseline for estimating the harm that will be caused by climate change in the future and for estimating the extent to which that harm results from the change in climate itself or from other changes in the social and economic context.

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2 "Climate variability" refers to the variation and extremes in weather at any point in time, whereas "climate change" refers to the trend over time in average weather conditions. Today's climate variability may or may not be in part a result of human-induced changes in climate trends.

- To address the lower left cell (social and economic change without climate change), projections will be needed of the anticipated changes in social and economic context over the period of the analysis. This will certainly include changes in population and population distribution in the area of concern as well as changes in the built environment, including buildings and infrastructure. If possible, it could also include other spatially linked changes; for example in the monetary value of physical structures in the area, in the kinds of economic activity going on, in the income generated by different kinds of activity, in the physical location of that activity, and in household incomes in different locations. Factoring in further changes — for example in culture, values, or political structure — goes beyond the scope of an economic analysis, although they may be important for choosing among adaptation options.
- For the upper right cell (climate change without social and economic change), the challenge is to project the physical impacts of climate change in the area in question. This is a complex issue that obviously pertains more to the physical sciences than to economic analysis; however, it is a key input into the CBA. Physical impacts of climate change are also where the most difficult uncertainty lies, particularly when dealing with a small area rather than average change over a larger area. In the terminology of DRR, local changes in climate are the hazard. In a specific place of concern, we would like to have an estimate of the probability of specific climate hazards; this is the risk to which that place is subject. In practice, of course, the scientific community does not fully have a handle on most hazards and their probability, hence the considerable uncertainty in this field. In the face of that uncertainty, some analysts design adaptation activities to be effective under a range of possible future scenarios, rather than based on the outcome considered most probable.

The combination of the two previous steps — in the dark-shaded cell — will lead to estimates of physical exposure to the hazard, meaning, how many people and what physical or economic assets will be at risk if the hazard occurs. The monetary valuation of the harm included in the dark-shaded cell is the baseline for analyzing the impact of adaptation activities; our adaptation strategy is trying to reduce that value.

Each of these steps could be carried out in many ways, ranging from fairly simple approaches to ones based on sophisticated models of climate change, population growth, macroeconomic change, impacts of climate on agriculture, infrastructure, or coastlines, and so on. The sections that follow describe some of the different ways in which the CBA can be carried out and show how different approaches are suitable for different contexts and levels of resource availability.

3.0 IDENTIFYING LOCAL CHANGE IN CLIMATE

The first step in the assessment of adaptation strategies is to assess the risks that climate change will pose to the area in question. The starting point of that risk assessment is to determine how climate change is actually expected to affect the area, or in DRR terms, what the hazard is and how likely it is. Predictions of the impacts of climate change are developed through a series of assumptions and analytical steps. Typically these steps are not the responsibility of the individual analyst evaluating adaptation strategies; in many countries the national government, academics, or donors carry out projections for the country as a whole, and results are available to those considering adaptation options. However, it is useful to understand what these steps involve in order to contextually place the assessment of adaption options.

1. The analyst needs to make assumptions, or choose scenarios, about future greenhouse gas emissions. Emissions are a function of global social and economic development, which determine what people consume and therefore how much they emit. The Intergovernmental Panel on Climate Change (IPCC) has developed a set of standard growth scenarios within its Special Report on Emissions Scenarios (SRES).[3] Most analyses of the impacts of climate change choose a few of these scenarios and predict climate change for each.
2. The emissions projections are input into global circulation models (GCMs), developed by climate scientists to predict the impact of emissions on physical parameters in the climate system: air temperatures, wind patterns and velocity, water temperature, and so on. These in turn lead to predictions of regional changes in temperature, rainfall, sea-level rise, and other parameters. There are five or six major GCMs produced by climate research centers around the world whose predictions differ from each other. We therefore have two sources of uncertainty in global climate projections, which stem from the choice of SRES scenarios and the choice of climate models. In addition, the further into the future the models predict climate change, the greater the uncertainty in the results. Similarly, extremely short-term change (e.g., what the climate might be like next year) also poses very large uncertainties.
3. The GCMs predict average climate change globally or over large regions. Predicting change in individual spots on the earth's surface is much more difficult. A great deal of international effort is focused on downscaling of the GCMs that make predictions at the national, sub-national level, or local level. Very broadly speaking, this can be done in one of two ways. [4] Dynamic downscaling takes the output of the GCMs as an input into regional meteorological models that predict how changes will affect local weather patterns. This method is extremely data- and computation-intensive, exceeding the capacity of many computer systems. As a result, it can only be used to downscale

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[3] Nakicenovic and Swart, 2000.

[4] Please visit http://www.southwestclimatechange.org/climate/modeling/downscaling for a brief overview of downscaling techniques for the layperson.

individual GCMs — and only for short slices of time — rather than to predict trends over decades. Statistical downscaling, on the other hand, uses statistics about local weather to build equations through which to translate the results of the global models to the local or regional level. It is much less data- and computation-intensive, and can be used to obtain much longer-term projections. It can also be used with "ensemble" GCM results, which average the predictions of a number of different GCMs. This approach removes the uncertainty associated with choice of GCM from the downscaled climate predictions. For all of these reasons, statistical downscaling is more often used than dynamic downscaling.

4. The probability of a specific hazard occurring is one of the key elements in placing a value on the harm it will cause. In theory, that valuation, referred to as the expected loss due to climate change, will be calculated as:

   Expected loss = (monetary value of the harm caused) x (the probability that the harm occurs)

For example, suppose the hazard in question is a modest flood of a type expected to occur in a given place once in 10 years. Its probability in any given year would be 10 percent, and the expected loss each year will be 10 percent of the total possible loss. However, if the flood actually occurs, the harm will not be the expected loss; it will be the total. The municipal authority considering adaptation options will therefore want to factor in the variance in expected loss; that is, the distribution of actual loss values around the mean. For an infrequent, high-cost occurrence, the variance will be high. In addition, different authorities may have different tolerance levels for risk; a more risk-averse community will be willing to invest more in adaptation than a less risk-averse community. In practice, however, analysts often don't know the probability of the hazard occurring, and the harm that would be caused by the hazard is an estimate. Moreover, risk aversion is inherently subjective and the organization making adaptation decisions must assign it based on their own assessment of their willingness to accept risk.[5]

The procedures described above are an optimal approach to estimating the impacts of climate change. They are sometimes referred to as a "forward-looking" approach because they are rooted in GCM predictions of future climate change. In some circumstances, when downscaled GCMs are not available or when the focus is primarily on estimating current rather than future risk, a so-called "backward-looking" approach is taken, based on historical data on weather-related disasters.[6] Trends from the past are extrapolated to the future, presumably with some estimated adjustment to account for expected impacts of climate change. Clearly this approach is not as well grounded in climate science as the forward-looking approach. However, when the objective is to get a quick and rough estimate of what may happen down the road, a backward-looking approach may be adequate as a point of departure.

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[5] In an after-the-fact empirical analysis of decision making in the face of risk, it could actually be possible to calculate risk aversion parameters if the analysts had data on a large group of individuals and how they really made decisions when facing a uniform cost of harm and probability of that harm occurring. But this is not the case with an organization making adaptation choices.

[6] Mechler and the Risk to Resilience Study Team, 2008, p. 25.

4.0 EXPOSURE: WHO OR WHAT WILL BE EXPOSED TO THE HAZARD?

To estimate the harm caused by climate change, and thus the benefits of different adaptation strategies, we need to know first who or what is exposed, and second, the monetary valuation of the harm people or areas experience. This section considers methods for estimating exposure levels; the next section will consider how to value that exposure.

Exposure to the impacts of climate change can be conceived of narrowly or broadly. A narrow perspective focuses on the direct impacts of individual disasters or changes: whose home will be flooded in a storm; which farmer will lose her crops to drought; or how that farmer's average crop yields will change in the long run. A broader perspective considers the indirect consequences of those disasters as well: how the economy will be affected by the construction boom replacing lost homes; how the price of food will change due to drought; or how nutrition levels may be affected as the farmer shifts to new plants that grow better in the changed climate.

4.1 GENERIC STEPS TO QUANTIFY EXPOSURE

Any CBA will have to choose among the many different impacts expected to be the most important. While we might want to measure "all impacts," in practice, the resources available for the analysis are limited, so the work will focus on the exposures expected to be the most important. The tools used to estimate exposure levels will also depend on the resources available; some tools take far more time and data than others. In general, however, a few steps will almost always be followed to quantify exposure to climate change:

Step 1. Current situation. Two kinds of baseline information are needed — physical and social — corresponding to the light-shaded cell of Table 1. The physical baseline includes current weather patterns and variability, sea level, storm surges, and so on. The social baseline includes the levels and/or spatial distribution of population, income ranges, types of economic activity, use of natural resources, location of structures, location and uses of infrastructure, location and level of economic activity, and so on.

Step 2. Climate change. Obtain information from downscaled GCMs about how climate change is expected to affect the area. Although this change could never be observed in the absence of complementary social changes — if it could — it would be represented by the upper right hand cell in Table 1.

Step 3. Social and economic change. Obtain projected data on population growth, migration, income growth, urbanization, deforestation, and so on. If there were no climate change, this would be captured by the lower left-hand cell of Table 1.

The ways in which Steps 2 and 3 will be carried out will depend on which climate change impacts are of specific interest and the resources available for the analysis. For example, if the topic of interest is coastal flooding, these steps will focus on which land, population, and structures will be affected by future storm surges. If the interest is the spread of malaria, the analysis will focus on where the climate will be suitable for spread of the disease and how many people will be exposed. If the interest is in agriculture, the focus will be on how expected changes in climate will affect crop yields. The analytical methods used will, in turn, be determined by the particular impacts of interest.

Step 4. Project exposure to climate change. Combine the projected changes in climate and in social context to determine who and what will be affected by climate change. This will correspond to the dark-shaded cell in Table 1.

These steps will be followed in somewhat different ways depending on the issues of interest and the resources available to carry out the analysis. The discussion that follows illustrates how they might be applied to four major areas of climate change impact: coastal flooding, agriculture, health, as well as ecosystems and biodiversity.

TABLE 2. OVERVIEW OF THE STEPS REQUIRED TO DETERMINE WHO OR WHAT WILL BE EXPOSED TO CLIMATE CHANGE HAZARDS

	Coastal Flooding	Agriculture	Health	Ecosystems and Biodiversity
Step 1: Current Situation	Use a geographic information system (GIS) to determine which land is now at risk of flooding, and who or what is there now.	Determine what is happening now with respect to the issue of interest; e.g., what is growing in a given place and how; or what the sources, prices, and technologies are for the current food supply.	Identify current spatial distribution of the disease of interest or of the species that transmit that disease to humans.	Locate key ecosystems in a GIS. Determine which communities now depend on those ecosystems, and how.
Step 2: Climate Change	Use the GIS to see which land will be flooded in the future, based on projections of sea-level rise and storm surges, combined if possible with data on local coastal features.	Predict how anticipated long-term changes in weather will affect the baselines suggested in the first step.	Determine how change in climate conditions will affect the survival of the disease itself or of the species that transmits it. If medicine does not yet know how the disease or the vector for transmission is affected by climate, further medical research will be needed.	Use downscaled climate data to predict which ecosystems will be at risk of floods, drought, and so on.
Step 3: Social and Economic Change	Obtain projections of population growth, migration, urbanization patterns, deforestation patterns, etc. to determine who or what will be affected by future floods.	Specific projections will depend on what issue is of interest; they may focus on changes in population, access to farmland, trends in non-food uses of farmland (e.g., biofuels), demand for food, prices, and other trends that may influence food supply from either the supply or the demand side.	Obtain predictions of population in the areas that will be exposed to the disease under future weather conditions.	Project growth of population dependent on the ecosystem.

	Coastal Flooding	Agriculture	Health	Ecosystems and Biodiversity
Step 4: Project Exposure to Climate Change in Future	Overlay the future floods with the future land use to assess the impacts.	Various models can predict the outcome, depending on the issues of interest. Agronomic models look specifically at how climate changes affect crop yields. Macroeconomic models will develop new balances in food markets based on trends in agricultural output, population, and so on.	Overlay spatial data on areas where the disease will be present with projected population data in order to determine exposure levels. Combine this with statistical data on the probability of catching the disease and with Disability Adjusted Life Years (DALYs) from the disease to estimate total impact.	Overlay population projections with projections of climate threats to determine how communities dependent on the ecosystems will be harmed.

The preceding table provides an overview of how these steps are carried out in specific areas, which are discussed further in the text that follows.

4.2 COASTAL FLOODING

Step 1. The important elements of the baseline for an analysis of coastal flooding relate to the topography of the coastline and to what is at risk of being flooded. This information is analyzed using a digital elevation model (DEM) within a GIS. The DEM is a digital map that shows the height above sea level, often in contour lines. It can be used to project what will be flooded; for example, if the sea rises three meters, then everything up to the three-meter contour will be affected. The GIS is used to overlay the DEM with other spatial layers showing where people live, where infrastructure is located, where resource-based economic activity is located, and so on. With this information, it is possible to determine who and what will be affected by floods at any given height.

The social context data used will depend very much on what is actually available (unless resources are available to collect primary data for the CBA, which often will not be the case). In an optimal scenario, we might have a DEM showing one-meter increments in elevation that can be linked to cadastral data – information about each individual parcel of land, including who owns it, and its assessed value or most recent sale price. The population data might be at the census tract level (in large cities a census tract could be a few blocks). The census data could include average income for the tract, while more detailed information, such as income distribution data within the tract, is generally not available for privacy reasons. With these data, the analyst could relate land areas flooded to census tracts. Based on this, the analyst could see exactly which parcels are likely to flood. With this information she could estimate the number of households or individuals that will be flooded, and the average incomes of people flooded out. Moreover, the analyst can calculate the exact value of the structures that will be flooded, based on the property value figures in the cadastral data.

Obviously, such detailed data will not be available in the developing world (nor, in many cases, in developed countries). More likely, the most recent census might provide population figures, and perhaps average income at the municipal level. There probably is no cadaster, or if there are property records in large cities, they are probably not digitized. The analyst might have to assume that population is evenly distributed across the municipalities, so if half of a jurisdiction will flood, then half of its population will be affected. Other methods would be needed to estimate the value of structures lost to floods. Each of these assumptions, while helping to populate a model, will also introduce uncertainty into the CBA.

Step 2. The important elements in the downscaled GCM data will pertain to expected sea-level rise and storm surges. These can be mapped on the DEM in the GIS to estimate which land is likely to be flooded in the future.

Step 3. The projection of the social context will depend very much on what kinds of data are available for the present, what kinds of projections are available from government organizations, and the amount of work that the analysts want to put into projections. If the time available for carrying out the CBA is modest, the analysts are likely to rely on projections already made by the government, or make very simplistic assumptions themselves about parameters such as a change in the density of urban settlements.

Step 4. The analyst will then overlay the different flood predictions and the new land use pattern to project who and what will be flooded in the future.

This is a fairly simply way to approach the analysis of coastal flooding, implicitly assuming that the sea level will rise by a uniform amount throughout the region under consideration. A more complex model of the impacts of storms could factor in local coastal features that change the way the sea hits the coast.

This approach is executed by using the Dynamic Interactive Vulnerability Assessment (DIVA) (Global Climate Forum, n.d.), a model used throughout the world to predict sea-level rise, the number of people who will be displaced, and the costs imposed. DIVA is based on a database of more than 12,000 coastal segments, including physical data about each stretch of coastline as well as social and economic data about the adjacent community. The user of DIVA can specify the SRES scenarios and global circulation models that they wish to use, and predict the coastal impacts of climate change in any country. DIVA was one of the tools used in the Dar es Salaam case described in Box 1.

BOX 1. MODIFYING GLOBAL DATA WITH LOCAL INFORMATION: THE DAR ES SALAAM COASTAL FLOODING CASE

Kebede and Nicholls (2011) have analyzed the impacts of coastal flooding on Dar es Salaam, which is considered to be the most vulnerable city in Africa. They discuss the local context of the city in some detail, explaining which areas are considered at risk based on: historical flood data and existing storm water drainage systems; the area threatened by erosion as sea level rises; and degradation of coastal resources due to economic activity.

Their actual quantitative analysis, however, is based on downscaling a global study of cities most at risk from sea-level rise (Nicholls et al., 2008) rather than building up from local knowledge. They project sea-level rise in future 100-year storms as a combination of projected global sea-level rise to 2070, the current 100-year storm water level, and projected natural land subsidence. These data come from a global database of 12,148 segments of coastline around the world, with variables describing the geomorphology and human settlements around each. This database is part of an analytical tool called DIVA, a model designed by the DINAS-Coast Consortium for analysis of the impacts of climate change-induced sea-level rise.

Using DIVA, Kebede and Nicholls build five different global sea-level scenarios including a “no climate change” option, all with the same SRES scenario. They project population and GDP growth for Dar es Salaam based on projections from other studies (Hanson et al., 2010). They only work with one urbanization scenario, but consider three distinct scenarios for spatial distribution of the future population of the city. Using that information, they work with a DEM and current data on population of each ward in the city in order to estimate current population within each one-meter contour line above sea level. This approach gives them 15 scenarios for how many people will be affected by flooding in the case of a 100-year storm in 2070.

Their estimates of the value of assets lost to flooding are simple. They do not use any empirical data about current structures in the city. Instead, they assume that the value of assets per person is five times GDP per capita, calculated based on purchasing power parity, which is a method that they say is commonly used in the insurance industry. Thus, their results do not include any information on income distribution or which income groups are most at risk. Moreover, because economic impact is a linear function of population impacted, it is not possible to use these results to trade off benefits to individuals against economic impacts in evaluating the effectiveness of different adaptation strategies.

Although Kebede and Nicholls know a lot about the specific conditions in Dar es Salaam, most of their analysis is based on the local portions of global databases or analyses, which are only slightly modified with local information. This approach is much more efficient than building an analysis framework that more specifically reflects the local context. While it will not be as accurate as a fully localized approach, it will require much less time, skill, and data, and may therefore be a more appropriate choice for many purposes.

Additional complexity might be added by bringing in information to predict seasonal or tidal variation. The analysis could incorporate land-based hydrology to analyze the contributions of both incoming seawater and rainwater runoff in flooding patterns. Whether this detail would be needed might depend on the spatial form of the land and whether flooding risks are expected to come primarily from ocean or rain. Hydrological models would also be used to assess inland flooding due to extreme storms and to analyze the impacts of drought on drinking water and irrigation.

The projection of population and structures in the region of interest could also be based on more complex models. For example, demographers might be modeling the determinants of rural-urban migration in the area, or city planners might be analyzing the determinants of urban land-use patterns. These models could be used to predict location of future population, rather than simply applying national projections. Or climate change factors might affect population movements. Demand for low-lying urban land could be projected to decrease relative to demand for high ground. This demand increases divergence in prices as extreme weather events become more frequent and there is a concentration of low-income people in flood-prone areas, while it decreases the value of the homes destroyed. Under most circumstances, building models to predict this kind of change will not be justified by adaptation analysis alone; but if someone else is already working the field, linking their analysis in to the climate change work could enrich the results without a major increase in cost.

4.3 AGRICULTURE

Step 1. The baseline will depend on the focus of the CBA. It could address adaptations designed to prevent total agricultural output from decreasing as the climate changes. In this case, the baseline will focus on: what is now being grown (both crops and livestock), where, in what quantities, and perhaps with what inputs. If the focus is broader and oriented toward food security in the country or region, the baseline will also have to factor in current food sources, how much output is sold versus how much is consumed by the grower, how much food is purchased versus how much is grown by the consumer, how much food is imported, the prices of different foods, and so on. Factoring in the food trade system will obviously make the analysis much more complex.

Step 2. The impact of climate change on agriculture and domestic food supply is primarily a result of changes in long-term trends rather than extreme events. Instead of focusing on storms and topography, the issue of interest in downscaling climate models will be how rainfall and temperatures are expected to change over time in the region of interest. If the adaptations are focused on food security rather than agricultural output, much broader issues of the impact of climate change on global food production and trading systems may also be relevant to the extent that the targeted community purchases rather than grows its food.

Step 3. If the analyzed adaptation options address local food production alone, then the impacts of the social context will be more limited than in the flooding case. Key issues may relate to continued access to farm land in the face of growing population pressure, or perhaps pressure to convert land to industrial biofuels plantations. If the adaptations are oriented toward food security, then the demand side of the market will be as important as the supply side. Projections will thus be needed for population, demand for food, and possibly food prices.

Step 4. If the focus is only on output, two broad modeling approaches have been developed to estimate how this may play out. **Agronomic models** simulate the growth of crops under a variety of conditions, including soil type, rainfall, temperature, chemical inputs, carbon fertilization,[7] runoff patterns, and so on. This kind of model is regularly used to estimate how changes in the climate will affect crop yields, soil hydrology, evapotranspiration, and other agronomic parameters. They are also used to predict how different crop varieties will perform as the climate changes — or when planted in new locations — in order to identify the promising agricultural practices for new conditions. These models are calibrated using historical relationships between input variables and crop yields, so they will be most effective when data are available to locally calibrate them.

Because these models do not account for autonomous adaptation, they will overestimate the overall impact of climate change on agricultural output. If the model is used to calculate yields as climate parameters change, it will not anticipate that some farmers in the region will start planting different varieties or crops on their own. Because of the autonomous change in composition of output, the total decrease in production is likely to be less than would be estimated by the models. On the other hand, the fact that they can factor in carbon fertilization is an advantage over other techniques. Moreover, they can easily be used to do sensitivity analyses by modifying individual parameters and running the model to see how the results change. Agronomic models then incorporate monetary costs into their assessment of impact by using market data on crop values.

Another approach to estimating the impacts of climate change on agriculture is the **Ricardian analysis**. This approach directly estimates how changes in climate parameters affect the value of output, without going through the intermediary of crop production models or estimates of yields. Ricardian analysis uses cross-sectional data about the behavior of farmers faced with a variety of different conditions — among them differences in weather — and runs regressions to determine the impact of each input factor on independent values, such as farmers' net revenues or crop and livestock choices. The general approach taken in all of these studies is to run regressions on the data to estimate coefficients for temperature and rainfall, which assumes that those coefficients based on spatial variation can be used to predict autonomous adaptation over time with climate change.

Several criticisms can be leveled at this approach. Since it is based on variation across space among farmers, it cannot capture changes that do not vary across space. In particular, it will not capture the impacts of carbon fertilization, since the concentration of carbon in the atmosphere will be uniform worldwide. It does not capture any changes in global food trade, which could be an explanation for behavioral differences among farmers in different places. Moreover, it does not offer a way to bring in change resulting from government adaptation work, such as identifying and disseminating new crops that are better suited to the region after the climate has changed.

4.4 HEALTH

Methods for predicting the impacts of climate change on health vary widely depending on the issues of interest. A fairly straightforward approach may be taken to look at the spread of certain diseases that may be affected by weather, such as malaria, cholera, or dengue fever.

Step 1. Identify the current spatial distribution of the disease of interest, and of the species that transmits it to humans.

[7] Carbon fertilization is a consequence of climate change; higher carbon concentrations in the atmosphere will be absorbed by plants, effectively fertilizing them and increasing their growth rates. While it is expected that this will occur, estimates vary widely about how much impact carbon fertilization will have on plant growth.

Step 2. From the downscaled GCM models, identify the change in spatial distribution of the weather conditions that permit survival of the pathogen itself or the species that transmits it; these will presumably relate to temperature, rainfall, or both. This step assumes that medical researchers know how disease vectors respond to changes in climate; for diseases about which this is not known, additional medical research will be needed. The DEM will not be necessary, although in some mountainous places, temperature and rainfall will change as elevation increases, so in fact topography will not be irrelevant.

The combined data on climate and disease distribution may have a temporal dimension as well; when disease exposure is climate-related, it is often seasonal, so the data must indicate for each location not only whether the conditions will be suitable for a given disease, but also for how many months of the year they will be suitable. Places where the disease is now present might find that the period of exposure is extended (or shortened) each year, in addition to new places becoming susceptible.

Step 3. From whatever sources are available, obtain predictions of population in the areas now at risk and those expected to be at risk in the future. (Some places where the disease is now a problem may no longer be suitable with climate change.)

Step 4. Overlay the disease distribution data and the population data to determine how many people will be exposed in the future. Link this to data (from other sources) on the probability of contracting the disease, if one is exposed, in order to estimate how many people will contract the disease in the future. This step will then be combined with public health information about morbidity and mortality from the disease, or the number of people likely to become ill and the number likely to die. These values are typically measured in so-called "disability adjusted life years" (DALYs), which combine the years of life lost to death from the disease in a country with a weighted sum of the number of years that people in that country live with the disease. This affords a single measure of the burden from the disease in each country. The weights are based on an expert assessment of the difficulty of living with the disease; for example, a year living with a very mild condition gets a much lower weight than a year with an extremely difficult illness. Statistics on these issues, and explanations of the DALY weights, are available by country and by disease from the World Health Organization (WHO).[8]

[8] Statistics are found at http://www.who.int/healthinfo/global_burden_disease/estimates_country/en/index.html. Explanations of the DALY weights are in World Health Organization, 2004.

BOX 2. PREDICTING THE SPREAD OF MALARIA IN EAST AFRICA BY COMBINING WORK FROM OTHER SOURCES

Hecht et al. (2011) estimated the impact of climate change on malaria distribution and the resulting costs, which combined detailed work by Tanser et al. (2003) with WHO data on DALYs. Tanser looked at the spatial extension of habitat suitable for both the malaria parasite and the mosquito that transmits it to humans under three SRES scenarios. Based on then-current population distributions, they used this information to predict the percent change in person-months of exposure to malaria by country throughout Africa. Hecht et al. linked Tanser's current person-months of exposure rates to current malaria DALYs from WHO, and projected this to 2050 based on population projections from the United Nations Food and Agriculture Organisation (FAO). The result was an estimate of changes in malaria DALYs in nine East African countries, under three different climate change scenarios.

Since the Hecht et al. study focused on costs and needed to compare health burden with the burden imposed by other impacts of climate change, these new DALYs then had to be given a monetary value. Many analysts would choose not to do this, since putting a cost on the loss of a life or on the burden imposed by disease is very difficult. Some studies value death or illness based on foregone earnings, which of course means that the health of rich people is considered more valuable than that of poor people. Unable to find any other studies that valued a DALY in East Africa, the Hecht study simply used projections of GDP per capita for each country to assign a value to the additional burden of malaria attributable to climate change.

This is a useful example of how a fairly quick assessment can estimate the impact of climate change that makes use of at least some country-specific analysis of the issue in question. This assessment took about a month of effort to carry out (as part of a larger study), which is fairly modest. Had it been necessary to do the work of Tanser et al. from scratch, the level of effort might not have been justified. But since it was possible to build on their study and the data available from WHO, an estimate could be made of growth in malaria relatively quickly.

As with the other examples (Box 2), analysts of health issues with the resources to do more thorough work will not rely on the WHO DALY data; these will typically be public health experts who will collect primary data to do much more detailed analyses of the impacts of climate change on health conditions themselves. Beyond the direct impacts of climate-related disease, climate change may have indirect consequences through its impact on food availability and nutrition, through the stress from extreme weather events, and so on. Health impacts of changes in nutrition could be estimated as a follow-on to agriculture and food trade models, while predictions of stress-induced health problems might be based on survey work on the extent of such problems at present. As with other issues, the level of detail that was warranted in order to predict the harm caused by climate change would depend on the particular problems in the region, the resources available for the analysis, and whether the decisions to be made based on the analysis results justified such detailed predictions.

4.5 ECOSYSTEMS AND BIODIVERSITY

The impacts of climate change on ecosystems and biodiversity combine elements of both floods and agriculture, but may be harder to quantify. In some cases, specific ecosystems may be physically destroyed by extreme events; these would be analyzed using steps analogous to those followed in the flooding example:

Step 1. Locate the ecosystems of interest and the communities dependent on them in a GIS. It will be important to understand *how* the communities depend on the ecosystem, since the losses are due to climate change. Thus the benefits of the adaptation strategies will vary depending this step.

Step 2. Use downscaled GCM data to determine which places will be at risk from flooding, drought, or other weather events. Depending on the place and the nature of the weather events, this step may call for complex modeling of hydrological and ecological systems rather than simpler projections of sea-level rise or coastal storm surges.

Step 3. Project the growth of the population dependent on the ecosystem. In a more sophisticated analysis, these projections may factor in expected social and economic change that affects the share of the population actually relying directly on ecosystem services.

Step 4. Overlay the location of the destroyed ecosystems with the future location of the population dependent on it to calculate how many people will lose access to ecosystem services and other ecosystem benefits (e.g., forest products, genetic diversity, and so on).

Other impacts on ecosystems may require more sophisticated analyses of systems in question. For adaptations focused on the capacity of ecosystems to provide a buffer to downstream water systems, detailed models of the relationship between forest cover and composition and downstream hydrology will be needed. On the other hand, some adaptations to loss of ecosystem services may not call for any of this analysis. For example, if pollination services may be at risk from climate change, it may be easier to simply replace them with commercial beekeeping rather than analyzing the exact impact of climate change on bees. If adaptations focus on replacing lost income from sale of forest products, it may be easier to simply assume that all of that income will be lost and to focus on alternate income sources, rather than analyzing the degree to which climate change affects ecosystem productivity.

Analyzing the impacts of climate change on biodiversity that does not directly benefit humans — but is considered to have inherent worth nevertheless — would be more difficult. However, if in fact the biodiversity that could be lost has no direct impacts on humans, then adaptation strategies will not be needed, so this analytical challenge need not be taken on in the context of economic assessments of adaptation.

4.6 CONCLUSION

This section has provided a few fairly simple examples of how exposure to climate change can be projected. Several important issues should be highlighted from these examples. First, the methods used to estimate exposure will depend on the type of adaptations being analyzed, both across and within broad areas of impact. Second, the resources available for carrying out the CBA to a large extent will determine the methods used; when resources are limited, as they usually are, it will not be possible to collect primary data or build complex models. The availability of resources will also influence the detail at which exposure is analyzed. When resources are limited, the study will have to be limited to direct impacts or those expected to be of greatest magnitude, and refinements of secondary impact pathways will not be feasible. Third, the quantified kinds of exposure will feed into the methods for estimating costs associated with that exposure, which is the subject of the next section.

5.0 VALUING CLIMATE CHANGE HARM AND ADAPTATION BENEFITS

Once exposure to the harm caused by climate change has been identified, it is necessary to convert it to a monetary value in order to build it into a CBA. This monetary value also measures the benefit of adaptation, which is expressed in terms of prevented harm. Therefore the discussion in this section applies to valuing both the harm caused by climate change and the benefits offered by adaptation. (See Table 3.) The discussion of benefits in the next sections considers issues related to how to measure or quantify them. As the discussion of the previous section shows, the estimation of the nature and extent of the harm is frequently closely linked to the estimation of its monetary value; however, there are many additional valuation techniques that can be separated from identification of the harm itself.

Some harm caused by climate change, such as decreased agricultural output or the destruction of buildings, affects goods or services that are sold in markets. For these impacts, harm is generally valued based on the market value of the items lost or destroyed. The value of this kind of harm is sometimes referred to as financial costs. Other harm, such as impacts on human health or biodiversity, affects items that are not sold in markets. This harm is referred to as the social cost of climate change. Economists have developed tools to estimate the monetary equivalent of social costs when markets can't provide that information. Financial and social costs combine to capture the economic costs imposed by climate change.

The following sections discuss methods for valuing harms that fall into three categories, in economic terms:

- Section 5.1 reviews how we estimate the annual value of things sold in markets – this could be incomes, or crops sold, or houses rented. It focuses on flows – that is, the income generated by a field rather than the field itself, or the rent paid on a house rather than the sale price of the house itself.
- Section 5.2 looks at how to estimate the annual value of things that are not sold – the harm caused by pollution, for example.
- Section 5.3 looks at methods for estimating changes in the value of assets – the field on which crops are grown, the forest from which trees are harvested, or the house that could be rented.
- Section 5.4 then goes on to discuss "benefits transfer," which is a way to obtain monetary values for any of the things considered in the first three sections without actually doing detailed primary data collection. It is not a new category of item to be valued; it is a different approach to valuing things in any of the three previous categories.
- Section 5.5 discusses the secondary or multiplier effects of the changes considered in Sections 5.1 to 5.3, focusing on how a change in one thing will have repercussions throughout the economy.

- Finally, Section 5.6 considers some specific concerns related to health impacts, which arise because of the ethical issues involved in putting monetary values on human health.

It should be noted that this subject is very broad, and each of these methods is the subject of extensive literature. This section provides a general description of the different approaches, but cannot begin to teach how they are used. A more detailed overview may be found in Chapter 4 of Metronomica Ltd. (2004). For information on actually applying any of these techniques, it is important to go into the much more thorough literature on actually applying each of them.

TABLE 3. APPROACHES TO VALUING CLIMATE CHANGE HARM AND ADAPTATION BENEFITS

Approaches to Valuing Climate Change Harm and Adaptation Benefits	When Applicable	Advantages	Disadvantages
Flows of marketed goods and services (using a variety of assumptions/economic tools)	When impacts of climate change are on marketable goods; and prices of those products can be modeled.	The economic impacts can be seen fairly clearly.	May lead analysts to overlook the impacts on non-marketed goods and services.
Measurement of contribution to flows of products that are marketed	When indirect impacts are understood and can be described through causal models.	Retains a mechanistic understanding of impacts and is linked to known prices.	As attribution becomes more difficult, uncertainty over values rises.
Travel costs methods	When people travel to locations to participate in recreation/ biodiversity/ experiences, and the willingness to pay for these services can be estimated from travel expenditures.	Relies on market-based proxy.	Limited to a small set of conditions where travel represents a sound estimation tool.
Contingent valuation	When goods and services are not marketed.	Presents a framework for valuing services and goods that do not have a market.	Very difficult to calibrate and is based on question bias.

Approaches to Valuing Climate Change Harm and Adaptation Benefits	When Applicable	Advantages	Disadvantages
Hedonic price method	When climate change affects value of land, structures, or other assets whose value can be modeled using regression analysis.	Data may be available in cadasters.	Limited to locations where land is bought and sold.
Benefits transfer approaches	When there is no available local information (and no funding to collect information), but other locations provide comparable results.	Relies on existing data and comparison of other studies.	Difficult to prove that conditions in another location are the same/similar enough for comparison.
Macroeconomic models (e.g., computable general equilibrium)	Modeling macro-economic impacts across sectors and regions.	Places climate change within broader economic modeling tools.	Data intensive and difficult to manage/understand how results are calculated.
Non-economic (e.g., DALY) – not examined in this paper	Particularly when monetizing, impacts may raise ethical concerns (health, biodiversity extinction, loss of rights, etc.) or become impossible.	Allows for a broader consideration of metrics for valuation.	The lack of economic values makes results difficult to compare with more easily computable economic impacts.

5.1 CALCULATING MONETARY VALUE OF CHANGES IN FLOWS OF MARKETED GOODS OR SERVICES

When climate change causes a decrease (or increase) in marketed production, it can, at least in principle, be fairly straightforward to value the harm it causes by applying market prices to the change in output. For agriculture, for example, these calculations build directly on the models used to estimate how changes in climate will affect output. The cost implications of the changes in output predicted by those models could be calculated in one of several ways, all of them based on knowing the price of the farmer's inputs and outputs and how input and output quantities will change with climate change, which cause changes in net farm income. How these calculations play out will depend on how the farmer responds to climate change. He could continue to grow the same crops but add additional inputs to get the same output as without climate change. He could leave inputs unchanged, but get less output than without climate change. Either of these would reduce profit margins, leaving the farmer worse off by a calculable amount. His losses might be so great that he can no longer continue growing the same crops, and he will switch to other ones. The cost of making that change will be a one-time cost that could be annualized as part of his input cost in the future; then the new margin — (output x sale price) less (inputs x purchase price, which includes the annualized cost of shifting crops) — would be compared with the old margin in growing the previous crop to estimate his loss (or gain). Many other details could also change in these calculations, but this generally is how foregone income would be valued.

Using this method requires access to data about inputs and outputs before and after climate change, which may be difficult to obtain. Moreover, it assumes that the farmers affected by this climate change are price takers – that is, their production is small enough relative to the markets in which they sell that they will not influence the market price. For developing country farmers exporting onto global markets, this is a reasonable assumption. For farmers selling in village markets, however, it may not be correct. If all farmers in the area produce less because of climate change, then the price of that product might rise in local markets because supply has dropped. To accurately estimate the impact of climate change on farmers' incomes, we would have to know the price elasticity of demand for the product so we could estimate the new market price and calculate farmers' incomes before and after climate change. Adding more complexity to the analysis, we might also want to know whether or how quickly less expensive substitute goods might appear on the local market, thus reducing demand for the expensive local crop and reducing its price. As in many cases, the feasibility of applying this method depends on the data and resources available for the assessment. Collecting the data and building the models required to make these calculations may or may not be feasible within the context of a given CBA.

A similar approach may be taken to estimating the monetary value of wild products harvested for sale on local, national, or international markets. These may include timber, fish, bushmeat, honey, or other gathered products. When climate change causes a decrease in the productivity of natural ecosystems, the harvester could respond by putting in the same level of effort and gathering less, or by putting in more effort to gather the same level as before. Again, if the harvester is a price taker, his income, calculated as (quantity gathered x price) less (quantity of inputs including time x price of those inputs), will drop, either because the gathered quantity drops, or because the quantity of inputs rises. If the only input that changes is the level of harvesting effort, and the harvester is not paid for his time, then the opportunity cost of time would be used to make this calculation.

When wild systems become less productive, sustainable yield will drop, so climate change could lead to depletion of a resource that was being harvested sustainably in the past. In this case, we can imagine a modest income loss over some period, followed by a drop in income down to zero once the resource is completely depleted.

When income is lost in this way, it is fairly easy to analyze the equity effects of climate change, or of adaptations that would prevent that income loss. If the available data capture the total value of household income, and if income distribution data are available for the area or country being analyzed, it will be easy to assess the income levels of those who are affected by climate change and place them within the broader income distribution. It could also be possible to do sensitivity analyses for the impacts of different adaptation strategies by looking at how much income loss each strategy can prevent. Where it is possible to quantify income losses from climate change and income generation through adaptive strategies, the analysis is well worth carrying out.

5.2 ESTIMATING MONETARY VALUES FOR FLOWS OF NON-MARKETED GOODS AND SERVICES

Many goods and services that are not marketed will be affected by climate change, and may be the target of adaptive strategies. For these goods and services, we must estimate a market value that will serve as a proxy for a price in CBA. The choice of estimation techniques depends on the nature of the item being valued, on the data available, and on the resources available for carrying out the CBA. See Box 3.

BOX 3. TIME HORIZONS AND DISCOUNT RATES

When the costs and benefits of an adaptation occur at different points in time, we must take that information into account in our analysis. The time horizon for the analysis will be determined by the period during which the adaptation is likely to have an impact. For hard adaptations such as walls or roads, this is the lifetime of the construction. For soft adaptations, it is much harder to identify. For example, if the adaptation is the development of a flood warning system in a coastal community, it will probably be necessary to pick a somewhat arbitrary period, one during which it is expected that the community will keep the system in operation.

The costs and benefits of the adaptation must be calculated out to the same period. When their occurrence over time is not the same as each other — for example, all costs occur at the beginning, but the benefits occur later — then it is necessary to discount both back to the present in order to compare them. Discounting is a way of taking into account the fact that a dollar today is worth more than a dollar next year, because if I have it today I can invest it, and next year I will have the same dollar plus the return on my investment, whereas if you promise to give it to me next year, I won't be able to earn that return. The difference in value between the dollar this year and next year is based on the discount rate, which is equivalent to the return on my investment. The higher the discount rate, the greater the value of the dollar this year relative to next year.

When the costs of an adaptation occur this year, but the benefits are spread out over a long period, the comparison of costs and benefits will be highly sensitive to the choice of discount rate. With a very low discount rate, the dollar of future benefits will be much closer in value to today's dollar of costs than it will be with a high discount rate. For this reason, in many analyses the choice of discount rate may determine whether costs exceed benefits or vice versa.

In general, the discount rate should be set at the interest rate that someone could earn if she were to invest the funds instead of spending it on the adaptation in question. However, in most markets there are many different interest rates on different kinds of funds, depending on who is borrowing, from whom, for what purpose, for how long, with what risks, and so on. In choosing a rate, it is advisable to sort through the funds markets in the local country and determine what the most plausible rate would be for the kinds of resources going into the adaptation activity. This rate is likely to be lower than commercial rates, and instead be closer to the subsidized rates for development projects.

Some environmental services involve protecting other resources from human or natural degradation. Mangroves and coastal marshes protect inland areas from storm surges. Forested hillsides protect downstream water supplies from rapid runoff and sedimentation, and protect people in the valleys from landslides. Values are usually estimated for these services through their **contribution to other products that are marketed and priced**. In some cases this estimation is relatively easy. Suppose, for example, that coastal buffers such as mangroves or marshes are overtaken by sea-level rise, and storm surges send occasional waves onto agricultural land. This may reduce the value of agricultural output on that land. The harm could be valued at the value of that output, and thus the benefits of adaptations to protect against storm surges would also be based on agricultural yield. Farmers might be willing to pay some amount each year to ensure that those adaptations are in place so as to ensure that their fields will not be flooded.

This estimation is not always so straightforward. Consider, for example, a hydrological system with a clean supply of water available downstream. With climate change, rainfall may become less frequent but much heavier when it occurs, which harms plant life on the slopes and thereby causes soil erosion and sediment in the water supply. The adaptation strategy might be to plant trees on the hillside to stabilize the slopes, while sequestering carbon at the same time.

We would quantify the harm caused by climate change, and thus the benefits of the adaptation, in terms of the harm caused by the sedimented water supply. However water often is not priced, and even when it is, the price reflects treatment and distribution costs rather than its scarcity value or people's willingness to pay for it, and it is usually the outcome of a regulatory decision by a public board that oversees the water company. The price of water will therefore not be a good measure of the benefits it provides.

This discussion suggests the very thorny nature of estimating values for some ecosystem services. If the water is used for irrigation, we could estimate its value based on its contribution to the value of agricultural output; in this case it would be the difference in value of output with the pre-climate change clean water versus the later sedimented water. (In fact, output might be higher at the later date, since runoff often contains nutrients that fertilize downstream fields.) If the water were used in factories, equipment might be installed to purify it first, so we would compare the profit margins before and after installation of that equipment to estimate willingness to pay for clean rather than sedimented water. But this approach creates a new problem. From the perspective of the factory owner, the sedimented water is the harm caused by climate change, and the new treatment equipment is the adaptation measure. If the owner wanted to do a CBA on that adaptation, the benefits (access to clean water, thanks to the treatment plant) would be valued in the same way as the costs (the amount paid to install the treatment plant), so the CBA would become redundant. This problem is discussed further in Box 4.

BOX 4. REPLACEMENT OR PREVENTION EXPENDITURES

Some analysts (e.g., Metronomica, 2004) go on from the market price-based methods to discuss other price-based methods for estimating harm caused by climate change, notably the cost of replacing things destroyed or preventing the losses from occurring. This approach may seem logical, but from the perspective of CBA, it raises questions about the difference between the harm caused by climate change and the costs of adaptation measures.

A simple example will illustrate this. Climate change might lead to the destruction of 10 hectares of coastal agricultural land. The market price of that land, which is expected to equate to the revenue it provides, might be $1,000/hectare, so its total value is $10,000. Anticipating climate change, we might consider as an adaptation measure the construction of a sea wall to prevent that land from eroding. The wall might cost $100,000 to build; this amount would be the prevention cost. Alternately, once the land is gone, we might consider a project to recreate it; that project might cost $50,000 — i.e., the replacement cost. The harm caused by climate change ($10,000) differs considerably from either of the adaptation measures we might consider to respond to the loss.

If we did a CBA of either of these adaptation measures, the benefit would be the recovery of the value of the lost land ($10,000) while the costs would be either $50,000 or $100,000. Neither adaptation would make sense, and we would reject them. However, if we had valued the harm caused by climate change based on the prevention or replacement costs, our CBA would become tautological, because we would have estimated the benefits based on the costs of achieving those same benefits. These figures are hypothetical, but they illustrate the fallacy, at least for cost-benefit purposes, in valuing harm based on the costs of preventing or making up from that harm. For our purposes, therefore, replacement and prevention expenditures cannot be considered valid ways to value the harm caused by climate change.

Another complication arises in the case of a poor downstream village. If they have no resources to treat their water or dig a well and pump up clean groundwater, villagers might simply have to drink unclean water, with resulting harm to their health. That harm might be quantified in DALYs, as discussed above, but to put a value on clean water, we would need a way to value a DALY. This issue is also thorny and is discussed later in this section. When water is so scarce that access becomes a matter of life and death, we may reach the limits of CBA altogether. In that case, if we are comparing adaptations that will ensure people enough water to survive, we are likely to use cost-effectiveness analysis to determine how to provide water at the lowest cost, rather than even thinking about comparing the costs and benefits of adaptation strategies in monetary terms.

Some non-marketed services may be easier to value than water. Where people travel to a specific place for recreation or other purposes, the value of that place can be estimated using the **travel cost method**, developed originally by Harold Hotelling for the U.S. National Park Service in the late 1940s. This method develops a demand curve for recreation based on observed variation in travel cost expenditures of visitors to a given site. The assumption is that at-site costs will be more or less consistent for all visitors, but the amount they are willing to spend to get there will let us identify different willingness to pay by different visitors. With the demand curve, we can estimate the consumer surplus of those who visit the site, and thus estimate the harm that would be caused if that site were destroyed or degraded by climate change.

When it is hard to find market-based proxies, analysts sometimes rely on **contingent valuation**. This approach involves surveying people about what they would be willing to pay to access something they do not have, or how much compensation they would be willing to accept to give up something they do have. There is extensive literature on how to do this, as the way in which the questions are framed can significantly bias the responses. One key issue is whether people are asked about willingness to pay or willingness to accept, since the responses are typically quite different. Other issues relate to whether the respondent is told that their willingness to pay would guarantee that the resource in question would be protected, how the payment mechanism is designed, and so on. Contingent valuation has been subject to considerable scrutiny on the grounds that, "asking individuals hypothetical questions only provides you with hypothetical answers" (Metronomica, 2004, pp. 4-47). While the economics profession has, on the whole, tentatively accepted the validity of this method, it is still open to question.

Contingent valuation may be the best way to estimate so-called option values, i.e., the willingness of people to pay for the existence of environmental assets that they do not expect ever to see or to benefit from. Option value actually gets at the concern of many conservationists for biodiversity; they simply feel that it should exist irrespective of whether it has any demonstrable value to humans, and they are willing to pay something to ensure that it does exist. Thus if climate change will harm biodiversity, the amount that conservationists would have to be paid to feel compensated for the loss (called "willingness to accept") would be a proxy for this kind of harm. Adaptation activities in this arena would aim to address the conservationists' loss of this option value. In practical terms, however, this kind of adaptation is likely to be of much lower priority than helping those who are more directly affected to adapt to the loss of resources essential to their day-to-day well-being. See Box 5.

BOX 5. VALUING IMPACTS OF CLIMATE CHANGE ON FORESTS AND MANGROVES

As part of the World Bank's extensive study of the costs of adaptation (World Bank, 2010b) Lange et al. (2010) have evaluated the costs of adapting to climate change impacts on the provision of forest products. Their work focuses on wood fuels and non-timber forest products (NTFPs) and on storm surge protection provided by mangroves, which explicitly chooses not to address watershed protection services, recreation, and biodiversity.

The analysis of forest products is very simple. The impact of climate change on forest productivity is obtained from a prior study (Sohngen et al., 2001), as modified by another analysis within the World Bank study (Sedjo, 2010). This work predicts availability of forest products based on changes in temperature, rainfall, and carbon fertilization. In most of the world, forest productivity is expected to grow substantially, largely because of carbon fertilization.

Consequently, climate change will not actually impose any harm on harvesting of wood-based fuels, at least based on a continent-scale analysis. In some arid areas, the impacts of climate change may be different, in which case climate change may place a burden on those dependent on fuelwood and charcoal. A more detailed study of this issue would have to work with more downscaled analyses of the impacts of climate change on forest productivity than was needed for the World Bank's global work. Moreover, the Sohngen/Sedjo analysis does not consider NTFPs. Because the involved species vary widely, it may not be reasonable to assume that their growth rates will parallel those of the forests; however, no data are available to assess this issue.

The analysis of mangroves focuses on the impact of climate change on the protection they provide against storm surges. Mangroves grow in intertidal zones where their roots are sometimes underwater and sometimes in the air. They serve as a buffer, substantially reducing the impacts of major storms on the land. Sea-level rise, by keeping the mangrove roots underwater all the time, could drown them, preventing them from providing this service. But mangroves also have considerable ability to move with changing sea conditions, which must be factored into the assessment of the impacts of climate change.

The mangrove analysis relies on the DIVA database and modeling tool discussed in Box 1 on Dar es Salaam. DIVA includes a module that assesses the potential for wetlands to migrate in response to sea-level rise. This module is based on features of the topography and how the land will evolve as the water rises. This feature is used to predict which mangrove areas will survive sea-level rise, and thus where they will continue to buffer against storms. The DIVA population data are used to estimate how many people will be at risk due to lost mangrove protection; the economic value of this loss is estimated as (GDP per capita) x (population at risk). Clearly this approach is a very simplistic way to estimate economic impact; a downscaled assessment would look more closely at the actual losses in the area in question.

The study suggests several strategies for adapting to this impact – essentially regenerating the mangroves, building protective structures, or moving people away from the coast. It cites anecdotal estimates about the cost of regenerating mangroves in different countries, but does not attempt to value any of these adaptations. Such estimates could be easier to make in a local study than in a global one, since they could be based on local conditions. Moreover, at a local scale it might be possible to rely on benefits transfer databases such as the Environmental Valuation Research Inventory (EVRI) discussed in the next section.

5.3 CHANGES IN VALUE OF ECONOMIC ASSETS

The previous sections considered how to value flows of income of non-marketed goods and services. An alternate approach to some of the same impacts considers how they affect the value of productive assets, such as land, buildings, or boats. The logic here is that the market price of a productive asset should be based on the net present value of the income that can be derived from it over time. If the expected income stream decreases (or increases) because of climate change, the sale price of the asset should decrease (or increase) correspondingly.

Where there is a well-developed market for the asset in question, the change in its value could be used to calculate the impact of climate change on that economic activity. Where an asset is at risk of being totally destroyed due to climate change, its market value can be used to value the harm, or in evaluating the benefits of adaptation strategies to protect it. This approach is likely to be viable when buildings are at risk of being destroyed by extreme weather events, especially when those structures are common enough that it is easy to estimate their market value.

When the impacts of climate change are less extreme, economists use the **hedonic price method**; the Ricardian approach described in the previous section is an example. The method estimates the contribution of each of a wide range of factors to the price of land or structures. Hedonic price analysis involves building a database about properties of the same type that have actually been sold, such as single-family homes, parcels of agricultural land, or commercial office buildings. Each parcel's sale price is the dependent variable. The independent variables include attributes such as size of the parcel; floor area of the structure; number of rooms; building material; cost of heating and cooling; date of construction; number of bathrooms; distance from amenities (schools, public transport, parks, "downtown") or disamenities (noxious industrial activity, major highways); and the presence or absence of such features as a beautiful view, a swimming pool, location in a flood plain, and so on. The analysis uses regression techniques to estimate coefficients for each of the attributes, measuring its contribution to the sale price of properties of that type. This approach can be used to identify the impact of climate-related factors (cost of heating or cooling, being in a flood plain, weather conditions for agricultural land) in the price of the asset, and thus the impact of climate change on asset values.

In the climate change context, this approach has been used to estimate the contribution of different farm characteristics to the net revenue from farm output. Climate variables will be a few among many input parameters; others will include soil characteristics, crops grown, inputs used, distance to markets, amount of sunlight per day, and so on. The spatial area covered by the database must be big enough that there is climate variation in the data. The coefficients for the climate variables in the uniform period for which data were collected are used as proxies for how future climate change will affect the value of agricultural output. Box 6 provides an example of the use of hedonic analysis to look at the impacts of climate change on livestock production; in that case, the dependent variable is non-monetary rather than monetary, but the principles are the same.

Hedonic price techniques lend themselves well to certain kinds of sensitivity analyses. If the adaptation strategies being considered involve introducing marginal changes in some of the attributes that were included in the regression analysis, then it is very easy to use the resulting coefficients to estimate the impacts of those changes. For example, if the analysis showed that, all else being equal, the value of a home is 5 percent lower if it does not have a sump pump, then this coefficient can be used to estimate the benefits of putting sump pumps into homes at risk of flooding due to climate change.

But hedonic pricing does not readily lend itself to any analysis of equity issues. To use it in that way would involve treating low- and high-value properties, or properties owned by poor and rich people, as separate types of assets, as well as carrying out separate hedonic analyses for each of them. With separate sets of coefficients as the outcome of the analyses, it would be possible to separately analyze the impacts of proposed adaptation measures on poor and rich people (or owners of low- and high-value properties). This approach could require much larger databases in order to have enough observations in each category to derive meaningful results. Moreover, this approach could make the results less reliable if the importance of most determinants of the sale price of the asset is not related to the total value of the asset.

BOX 6: USING THE HEDONIC PRICE TECHNIQUE TO ESTIMATE THE IMPACT OF CLIMATE CHANGE ON LIVESTOCK

Seo et al. (2009) used the hedonic price approach to look at how climate change would affect livestock production in Africa. Their focus is quantitative rather than monetary; they are interested in how the distribution of species would change across agroecological zones facing different effects of climate change. Hecht et al. (2011) subsequently applied price data to their results to estimate how these shifts would affect livestock-based incomes in nine countries of east Africa.

Seo et al. look at the distribution of five species (beef cattle, dairy cattle, sheep, goats, and chickens) across 16 different agroecological zones. This approach does not begin by predicting the actual impacts of climate change in the regions of interest. Rather, it uses current variations in temperature and rainfall across the 16 zones to develop coefficients for current livestock distribution that the analysts believe can also be used to predict changes in livestock distribution when temperature and rainfall levels change in the future. This approach enables them to predict, for each agroecological zone, the expected change in livestock distribution for a given change in climate parameters. The structure of their analysis would make it possible to redo the calculations with different future climate scenarios, although in fact Seo et al. only make predictions for a single scenario. Their predictions take the form of percent changes in the number of farmers for whom each species is their primary livestock holding, which reflects the suitability of future climate conditions to each animal. Hecht et al. then applied those figures to current livestock distributions and prices in each agroecological zone (based on FAO data for the nine countries of interest) to estimate the change in value of livestock due to climate change. The result of this analysis suggested that climate change will lead to quite moderate decreases in livestock value in the Horn of Africa and the mountainous regions of Rwanda, Burundi, Uganda, and western Kenya and Tanzania, while it will have virtually no impact on livestock value in the plains of Kenya and Tanzania.

This example is interesting because the Seo work distinguishes among climate change impacts in different agroecological zones. However, in order to simplify what is already a very complex analysis, they chose as their dependent variable the share of farmers in each zone for which each species is the primary livestock holding. In reality, however, many farmers probably have a mix of species. Nevertheless, building a model that could consider the full set of species held by each farmer would be far more complicated, so this simplification was necessary.

This example also shows how data and results are shared among studies. While Seo et al. had resources to carry out a detailed analysis, the Hecht et al. work was more limited in scope and had to rely on inputs from other sources. The Seo et al. study was a good fit because it looked at agroecological zones, which matched the Hecht et al. approach. It was less good, however, because it did not include camels, which are very important in East Africa, particularly in the Horn of Africa. Seo et al. were looking at all of Sub-Saharan Africa; in this broader area, camels have a minor presence, but their exclusion was not entirely appropriate for an analysis focused only on East Africa. This kind of problem frequently arises when studies must borrow from each other, but such borrowing is unavoidable when resources for CBA are limited.

5.4 BENEFITS TRANSFER

Many analysts interested in valuing the impacts of climate change do not have the time or resources to carry out the studies described here. Instead of seeking primary data about their own site, they look to other research to identify values similar to the ones they would like to estimate, and apply them to their own work. This approach does not measure anything different from the issues discussed in the previous section; it simply can be an easier way to obtain reasonably accurate values, with less primary analysis required. Benefits transfer may be done in many ways, and at many stages in the analysis. The ideal might be to find another study that looks precisely at the questions of interest, in the same country or one that is quite similar. Finding an array of other studies that provide different values that can be transferred into the new analysis in a wide variety of contexts is more likely. There is no one way to transfer results from one study into another; it entirely depends on the questions to be answered by the new study, and on the other available work that provides data or results that could be applicable elsewhere. This idea is illustrated by many of the examples provided in the Boxes 1-9 in this paper, which show how studies routinely combine and build on each other's data and results rather than attempt to begin from primary data.

In order to facilitate sharing of valuation work that could be useful for benefits transfer, the EVRI has been created by Environment Canada, with input from a number of other countries (Environment Canada, n.d.). EVRI is a searchable database of valuation studies that analysts can use to track down other work that may give them values that they can transfer to their own area. This is a useful resource when seeking to value the harm climate change causes to environmental resources and biodiversity.

5.5 INDIRECT IMPACTS

The approaches considered so far apply to estimating monetary value for harm that is directly caused by climate change. The broader economic impacts of climate change result from the multiplier effects of the direct costs, as they filter through the economy. Although these impacts are likely to go beyond the scale of the CBAs carried out for adaptation projects, they may in fact be greater in monetary value than any of the direct impacts we have discussed so far, so it is useful to know something about them. Some are relatively clear:

- If a major port such as Mombasa were to become unusable due to a massive storm surge, it would have major implications for imports throughout East Africa; for the economies of countries in the region dependent on goods passing in or out of the port; and, to a lesser extent, for the economies of countries shipping goods through Mombasa for sale throughout the region.
- If many structures are destroyed in a major flood — in addition to the immediate losses — new jobs will be created to replace the structures, with positive repercussions for the local economy.
- More gradually, and with more time for autonomous or planned adaptation, the shifts in agricultural output resulting from climate change may have a variety of multiplier effects over time. The demand for agricultural inputs may shift, some farmers may move into other income-generating activities, countries less able to grow their own food may buy more on global food markets, and those that are better able to grow crops will sell more.

Analyzing this kind of indirect change is done using a variety of macroeconomic models that represent the overall structure of the economy. Computable general equilibrium (CGE) models are top-down aggregate models showing the interactions among sectors in a single country or in global markets, building in demand and production functions that are calibrated using real world data. Once constructed, the model can be used to predict the impacts of changes in independent variables, calculating the level of activity in each sector, employment, and consumption in the changed situation.

Input-output analysis uses economic data in the form of a "social accounting matrix," which shows what each sector of the economy purchases from each other sector, including purchases from households (the labor market) and purchases by households (final consumption). This matrix can be used to calculate the impact on each sector of the economy of an exogenous change in one value. It can also be expanded to build into the analysis the impacts of economic activity on the environment, for example, by adding rows to the matrix that show the greenhouse gas (GHG) emissions of each sector of the economy as a function of its activity. The structure of the interactions among sectors in an input-output matrix is determined by the underlying data and is assumed to be unchanging, whereas in a CGE model, the analyst can make and change assumptions about how those relationships are structured that use empirical data to test the accuracy of their assumptions.

Macroeconomic analysis is complex and data-intensive, and is likely to go beyond the scope of most CBAs for adaptation. This makes it difficult to build macroeconomic impacts into the choice among adaptation options. Where the models are already in place and being used for other related purposes, however, using them to look at the harm imposed by climate change or the impacts of different adaptation options may be worth considering.

In practice, when actually estimating the harm caused by climate change to environmental assets or the goods and services they provide, analysts will use a combination of these methods. The general strategy is to identify all of the goods and services provided by the asset at risk, then value each one separately and sum the results to get the total value of the resource, which economists call "total economic value."

5.6 MONETIZING HEALTH IMPACTS

The monetization of health impacts requires separate attention because of the ethical issues involved. When we are dealing with the death of a specific known individual, most people would say that it is wrong to make monetary trade-offs between that life and something else of value. However, both individuals and societies regularly make decisions that involve trade-offs between reducing the probability of death, illness or injury, and spending the resources on something else. This notion implies that we do implicitly use the concept of the "value of a statistical life" or "value of a prevented fatality," and so the concept can be used in CBAs.

The harm caused by health impacts essentially has two components for valuation purposes:

- Foregone earnings of the affected person. Using this as a measure of the benefits of adaptation would imply that the life of a rich person is worth more than the life of a poor person. In practice, more money is spent protecting the lives of rich people, because they have the resources to put into their own protection. As a matter of public policy, however, this would be considered unacceptable.
- Direct expenses, such as medical and funeral expenditures, and special food or equipment needed.

Measures of the value of reducing the probability of injury or death are qualitatively different from foregone earnings or direct expenses in that they focus on willingness to pay to prevent harm rather than the monetary value of that harm once it occurs. Several methods may be used:

- Evidence from situations where people can choose to purchase equipment that would reduce their chance of death or injury can be used to estimate their willingness to pay to lower risk. This could include optional safety features in automobiles, bicycle and motorcycle helmets, safety features that add to the cost of power tools, or higher prices for homes that are not in flood plains.
- Hedonic price approaches can be used to assess the wage premium required to get people to do dangerous jobs.

- Contingent valuation can be used to estimate what people would pay to reduce the probability of accidental death by some stated percent.

All of these methods — both for valuing harm that occurs and for estimating willingness to pay to reduce the probability of harm — suffer from the problem that they will be related to income. Rich people can afford to spend more to avoid risk (or require more compensation in order to take risks). Consequently, all of these methods will suggest that rich people value life more highly, or that their lives are worth more than those of poor people. When analysis is being carried out or decisions made at a large scale, the values obtained from these methods can be averaged across the income distribution of the country to come up with a single average figure to use in national decisions. This may smooth out the income effect in valuation. However, when the decision is being made at a local scale, or a choice is being made about where to invest in preventing mortality or morbidity, this equity issue can create significant distortions if the statistical value of a life is used as a basis for deciding about adaptation investments.

For this reason, when it comes to health impacts, it is often more appropriate to use cost-effectiveness analysis rather than CBA to assess adaptation strategies (which relate expenditures on adaptation to reduction in DALYs), rather than to the economic benefits of improved health or to willingness to pay to avoid the risk of harm.

6.0 INTEGRATING BENEFITS AND COSTS INTO THE ANALYSIS

Sections 4.0 and 5.0 have worked through how to quantify exposure to climate change and put a monetary value on it. This section uses that information to consider the elements that go into the CBA of one or a group of adaptation strategies. Those elements fall into four categories:

- Direct financial expenditures required to implement the adaptation;
- Indirect or social costs that its implementation may impose;
- Direct benefits, i.e., the reductions in the harm whose monetary value was discussed in the previous chapter; and
- Any other unrelated benefits that it may bring to the immediately involved community or to others.

These four elements are discussed first with respect to hard adaptations, and then with respect to soft adaptations, because they play out somewhat differently for the two kinds of interventions. The section then goes on to discuss two other issues in CBA for adaptation: how to use the tool to consider a portfolio of interventions, and the implications of integrated versus discrete adaptation interventions for CBA.

6.1 HARD ADAPTATIONS

Hard adaptations are physical structures whose purpose is to prevent the impacts of climate change, or whose design incorporates elements that prevent those impacts. They may include such capital investments as constructed or planted barriers that prevent floods, infrastructure engineered to resist the impacts of future weather patterns, houses on stilts, air conditioning in places that didn't used to need it, or houses designed with natural cooling features. Some of these solely or primarily exist in order to deal with climate change, while others primarily serve other purposes but have been designed to be usable as the climate changes. They may be either human constructions or planted natural "structures" such as forests or mangroves.

The direct costs of hard adaptations are quite straightforward and are estimated in the financial and engineering studies that precede their construction. They basically include the capital and labor required to build the structure, the financing costs, and the ongoing labor and materials required to maintain it in good working order over its useful life. Since someone must pay all of these costs, they should be well-identified and easy to track.

The indirect costs of hard adaptations often are also identified in the course of planning the project, though environmental and social impact assessments, public input processes, and other legal requirements are applied to large-scale projects. A sea wall offers a useful example of the way in which hard adaptations can impose both indirect monetary costs and non-marketed impacts unrelated to the purpose of the wall.

- If the wall changes the way water flows along the coast, it may affect sand deposition downstream, changing the form of beaches, which may be important for the local tourist industry. This is an externality that will impose marketed economic costs on hotel operators and others in the industry as they lose visitors because their beach disappears. This cost will be incurred throughout the life of the sea wall, perhaps increasing over a few years and then leveling out. Such impacts can be identified through public input processes as well as engineering studies. They will probably be valued based on the foregone income methods discussed in the previous chapter.
- The changes in water flows might also affect the growth of sea grasses, with consequences for marine habitat, fish spawning, food supplies for water birds, and so on. These costs would be valued using the environmental valuation methods already discussed; however, placing a monetary value on the loss or creation of marine ecosystems is difficult, especially if those ecosystems do not provide goods or services directly to adjacent populations.
- The impacts on sea grasses might also have negative impacts on the local fishery. These, like the consequences of reduced sand deposition, will be marketed external costs valued based on foregone income. They may also increase over some period and then perhaps level out.
- The response of local fishermen to the changes brought about by the sea wall will be a secondary impact of the wall. Perhaps they will switch to harvesting a different species, which necessitates the purchase of new equipment. Those purchases might also be considered marketed external costs of the sea wall, but they will be somewhat mitigated by the revenues from the new species harvested.
- The lack of familiar fish species might lead to a change in local diets, with nutritional consequences for the community. The resulting health impacts might be thought of as third-level impacts of the sea wall, and could also be accounted for in the CBA. However the analysts will have to draw a line somewhere to limit how far they want to go in spinning out the web of consequences of the sea wall. They will draw this limit based on how much time and money they have to do the analysis and how important they expect these indirect effects to be.

The analysts will measure all of the direct costs, and all of the indirect costs that they wish to include in their CBA. Because these costs occur at different points in time, they must be discounted back to the present, after which time they will be summed in order to arrive at a total cost figure for the adaptation.

The process will be similar for the benefits of the adaptation. Continuing with the sea wall example, the engineering specifications for the project will usually require that it perform at a specified level, which will define the direct benefits of the adaptation. For example, the engineers may be required to design a wall that will protect against storm surges that are expected to have a 2-percent probability 50 years from now. Using the analysis of the impacts and costs of coastal flooding discussed in Section 4.0 and 5.0, the cost benefit analysts can easily see who will be expected to benefit from this work over the life of the wall and what the monetary value of those direct benefits will be. The benefits will accrue over the life of the sea wall, and therefore must be discounted back to the present using the same discount rate as was used for the costs.

The sea wall project will also have an array of indirect benefits:

- The wall might create a sheltered pool where people can swim safely. The community might put in bathing facilities, hire a lifeguard, and charge a small sum for people to swim there. This would be a marketed indirect benefit of the wall. Alternately, people might simply go there to have a swim at no cost, with no facilities; their willingness to pay for this opportunity if they had to pay for it would be a non-marketed benefit of the wall.

- The construction of the wall will create many jobs over a few years; its maintenance will create a few jobs over its useful life. Those holding the jobs will spend their income, with multiplier effects throughout the economy. If macroeconomic models or input-output tables are available for the country, it may be possible to use a construction industry multiplier from another study to determine how much this element will stimulate the economy, so that this indirect benefit can be included in the CBA.

These consequences may be a double-edged sword, however. If the multiplier effects from constructing the wall are included in the analysis, any other multipliers must also be included in order to be consistent. For example, if there were no wall, and houses were destroyed in the ensuing floods, the houses would be rebuilt, thus creating new jobs in construction. The earnings of those constructions would be spent, and they would have a multiplier effect. If we include the multipliers from building the wall on the benefit side of our CBA — increasing its benefits — we also must include the multipliers from rebuilding houses on the other side of the analysis. That approach would reduce our valuation of the harm caused by climate change, which, in turn, would reduce the benefits (foregone harm) of the wall. It may be simpler (and sufficiently accurate) to omit all calculation of multiplier effects, rather than putting in the effort to ensure that any multiplier effects included on one side of the analysis are matched by the corresponding — though not necessarily equal — multipliers on the other side.

Like the costs, the benefits of the project will be measured, discounted back to the present, and then summed. The total costs and total benefits will then be compared. If costs exceed benefits, the project will be dropped. If benefits exceed costs, the analysts can go on to compare it with other proposed adaptations, and to examine the non-economic concerns that also will be important in deciding whether to go ahead with the project.

6.2 VALUING SOFT ADAPTATIONS

Soft adaptations can be more complex to analyze than hard adaptations, because it can be harder to pinpoint the benefits that may be attributed to them. The term "soft adaptation" is used rather intuitively to refer to any approaches to adaptation that do not fall into the somewhat more specific definition of hard adaptation. That is, a soft adaptation may be anything that does not primarily involve construction (or plantation) of physical objects designed to block or prevent negative impacts of climate change. The World Bank glossary of climate change terms refers to soft adaptations as those focused on "information, capacity building, policy and strategy development, and institutional arrangements." (World Bank, 2013). This does not actually categorize the components of soft adaptation, as these activities may overlap, but it offers a fairly useful definition if understood broadly, and perhaps slightly added to:

- "Information" will include research and extension on adaptation strategies, data collection, improving information on local impacts of climate change (downscaling GCM models), strengthening decision support tools, and so on.
- "Capacity building" would including educating individuals, communities, and organizations on use of climate information and decision tools, helping government agencies assess how climate change will affect their work and how they should plan to adapt, as well as related activities.
- "Policy and strategy development" would include preparing national or sub-national adaptation plans, implementing regulations or construction codes that mandate inclusion of climate change risk in building and infrastructure design, introducing financial incentives to encourage and assist those who

will have trouble adapting otherwise, and a wide array of other measures to support and encourage adaptation.

- "Institutional arrangements" could include any number of activities designed to support institutional adaptation, from helping communities identify and implement priority actions to helping national ministries collaborate in their adaptation work.
- Insurance systems are not included in this definition. Insurance systems share risk across a pool of people so that no one person will be hurt as much, but do not actually do anything to reduce total risk. They should be added to the list of soft adaptation measures.

The elements of a CBA are the same for soft as for hard adaptations. The direct costs are the expenditures by institutions taking the initiative to help vulnerable communities introduce adaptive measures. In comparison with the hard adaptations, these adaptations are likely to involve more expenditures on labor and little or none on capital, as much of the work will involve activities such as community organizing, research, policy analysis, data collection, or communications, rather than building or planting things. The direct costs of soft adaptations will not greatly vary across the different types of activities involved. Because these are expenditures made by agencies with functional accounting systems, they are known and can be measured; although, to the extent that these adaptations involve small communities in the field, their expenditures — often in kind rather than in funds — may be harder to identify and quantify.

The direct costs of soft adaptations may include non-marketed inputs that were less important or non-existent for hard adaptations. These include the time of communities targeted by the soft adaptations—time spent in training, in meetings to discuss priorities, or in implementing some of the adaptation measures. This time is a direct contribution to the adaptation, not an indirect cost. Unless they are paid for their time, it must be valued based on its opportunity cost, i.e., based on the earnings foregone, because this time goes into adaptation activities rather than paid work. Often this community contribution is not considered a cost; but in this cost-benefit framework, it should be.

Indirect costs may be less of a concern for soft adaptations than for hard ones. Because they do not involve structures, they are less likely to cause physical impacts that harm the environment or affect other people's use of it. They could pose more subtle risks, such as:

- A policy strategy that offers partial subsidies to coastal dwellers to raise their houses out of reach of floods could end up providing funds to people who would have spent their own money to do this, even without subsidy. Because they received that money, it could not be used for other important public purposes.
- The introduction of insurance schemes that buffer households or businesses against climate change risks may encourage them not to take other rational steps to prevent harm, because they know that they will be compensated if a disaster occurs.
- A community-based process to identify and prioritize adaptation needs could be derailed by community leaders, and not end up benefiting those who most need help.

These kinds of risk and the associated costs are very hard to anticipate in a CBA in advance. After all, if these outcomes could be anticipated, they would be prevented. For this reason, the analysis of soft adaptations may not include much in the way of indirect costs.

Identifying and quantifying the benefits of soft adaptations is more difficult. Those who design and implement them know what they aim to achieve, but it can be hard actually to quantify and value what they do or will accomplish. This notion is particularly true of adaptations that aim to broadly increase community resilience or build the capacity of government to help others adapt. Consider, for example, the UK Climate Impacts Programme (UKCIP) Climate Adaptation Wizard, used to guide local or national government agencies through a process of anticipating how climate change will affect their work and deciding how they will adapt.[9] The costs of the creation and use of the adaptation wizard are relatively easy to calculate; essentially they consist of government staff time and perhaps consulting contracts. The benefits of this work will be seen in the ways in which government agencies using the wizard anticipate and adapt to climate change in their work. The individual adaptation strategies that they consider can be analyzed in a cost-benefit framework as discussed in this paper, but, is there any way to quantify the benefits of the wizard itself? Indicators of its use could easily be calculated; the number of agencies that went through the wizard process, developed adaptation plans, and then chose and implemented adaptation strategies, for example. But this fact does not help us identify specific climate change harm that was averted as a result, which would allow us to compare the benefits of the wizard with the costs of creating and using it.

Even if the CBA were carried out *ex post*, and averted harm could be quantified, it would be difficult to determine how much of the averted harm should be allocated to the climate wizard, and how much to all the other inputs into the adaptation process. If the full averted harm were attributed to the wizard, that would mean the other inputs — the time of staff who used the wizard and then designed and implemented the adaptations, the time of the local community, and so on — did not contribute at all to averting harm. If the full benefits were attributed both to the wizard and, separately, to the other inputs into the resulting adaptation, then when summing total benefits, there would be double counting, since the same averted harm would be attributed both to the wizard and to the other inputs. Obviously, the wizard is one among many inputs into adaptation, and in some sense they are all a package. However, the structure of CBA, when applied to a specific adaptation strategy like the wizard, would require us to separate out which benefits resulted from each input.

The same problem would arise with other soft adaptations. Consider an adaptation focused on downscaling the GCMs and making the results widely available. The analysts could look at use of the results and could quantify the benefits from the projects that used the results. But it would not be correct to attribute all of those benefits to the availability of downscaled GCMs, as that information is only one of many inputs into the projects. This difficulty in determining how much of the benefit of an adaptation activity should be attributed to a single input is a limitation of CBA for evaluating many soft adaptations. This limitation is an argument for using other analytical tools along with or instead of CBA.

Adaptations that aim to build capacity may be difficult to assess for another reason as well. While everyone may agree that building government agency capacity to address climate change issues is a good idea, there may be less agreement about the best way to do it. The UKCIP has chosen to focus on developing an array of online tools that agencies can apply. They could instead have chosen to concentrate primarily on holding in-person training courses for government officials, or on providing technical experts to guide individual agencies instead of sending them to the wizard. Unlike engineering projects, where experts can predict with fair accuracy what each structure will accomplish, a quantitative analysis of the differences between online tools, training courses, and technical assistance is not likely to be possible. While there is certainly literature on the best ways to carry out this kind of activity that can help in thinking through program design, it is not likely to be rigorous enough to actually allow quantitative predictions of the outcomes of different approaches. For all of these reasons, CBAs of this kind of soft adaptation may have to be complemented with other analytical tools such as cost

[9] See UKCIP (2010) or http://www.ukcip.org.uk/tools/. This set of tools may offer a useful model for U.S. Agency for International Development (USAID) missions considering how to build host country government capacity to anticipate and adapt to climate change.

effectiveness analysis, multi-criteria analysis, or participatory processes to work through the choice of adaptation strategies with the stakeholders who will be involved.

Soft adaptations that involve setting construction standards may be a bit easier to address in a CBA because they essentially could be analyzed as a package of hard adaptations. Consider a proposed adaptation that consists of changing design codes across the country to require incorporation of expected climate change impacts. This policy change might be evaluated through a rough bottom-up approach, estimating the expected future stream of infrastructure projects, how the new codes would change the financial costs of each, and how much harm those codes were expected to prevent. This evaluation would depend on a lot of assumptions about the future projects, making the results quite uncertain; but this approach is still more tractable than other soft adaptations.

One study, carried out by Hughes et al. (2010), has taken an alternative approach to the specific problem of analyzing the impacts of a change in construction codes. That study begins with an econometric model of infrastructure demand, calibrated using panel data[10] on infrastructure expenditures across both time and space, which estimates the implications of climate change for the per-unit cost of infrastructure. The analysts estimate how demand for infrastructure will change over time with and without climate change, and then use the results of the econometric model to calculate the costs of the infrastructure that will be demanded if the climate changes.

Such a model could be modified based on the standard to which building codes are set, permitting recalculation of expected costs under increasingly strict standards (Hughes et al., 2010, p. 32). This option is useful because it permits the analyst to compare the costs of adaptation with standards set to different points in the lifespan of the infrastructure to be built. For example, suppose a road is expected to last 50 years. If it is designed for the climate conditions 40 years from now, it will be overdesigned for most of its life; no one will be harmed due to its failure until the last 10 years of its life, but for the first 40 it will be overdesigned and consequently cost more than it needs to. If it is designed for climate conditions 20 years from now, then costs will be lower, but more people may be harmed during the life of the road. Being able to compare the costs of different design standards is a potentially valuable undertaking. However, building this kind of model would be extremely expensive in terms of time, skills, and data, and is likely to be beyond the capacity of most adaptation CBAs.

6.3 PROJECTS VERSUS PORTFOLIOS

So far we primarily have focused on assessing individual standalone adaptation strategies. Under some circumstances, it may be useful to assess a portfolio of strategies as a group, rather than assessing each of them separately. Whether this makes a difference in our assessment process depends on how the items in the portfolio relate to each other. In general, a portfolio of adaptations will be assessed by assessing the individual elements, summing the benefits, summing the costs, and then seeing how benefits relate to costs for the whole package. This process is sometimes called **cumulative cost benefit analysis** (Khan et al., 2012).

This cumulative CBA will be straightforward if there are no links among the different items within the portfolio. If, however, they are interrelated, and the success of one is enhanced by carrying out the others, then the links among them must be taken into account in the analysis. For example, several

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[10] Panel data analysis uses data on cross-sectional groups of people observed over time. This technique makes it possible to observe variations across the groups and see how different groups evolve differently over time in response to the same stimulus – in this case, climate change. See http://www.nyu.edu/its/pubs/connect/fall03/yaffee_primer.html for more information on panel data.

activities may depend on being able to share an investment that could be too expensive to be justified by any one of them alone. The activities might be sequential, with each only making sense if it follows the preceding one. Certain benefits might occur only if two separate activities are both carried out, even if each of those activities separately leads to other benefits. In this kind of situation, the calculations would have to track how each item in the portfolio links to the others, seeing which are linked and which might be able to stand on their own. Where there are links among activities, their costs and benefits have to be calculated jointly, which essentially treats that group of activities as if they were a single activity without double counting any expenditures that contribute to several activities, or any benefits that result from several activities. If any activities can stand alone, their costs and benefits can be calculated separately. The costs and benefits of the portfolio as a whole would be calculated as the sum of the costs and benefits of its stand-alone and linked components. See Box 7.

BOX 7. A PORTFOLIO OF HARD AND SOFT ADAPTATIONS ON THE ROHINI RIVER

Kull et al. (2008) looked at flood control strategies on the Rohini River in Uttar Pradesh, India. Their work examined the performance of flood control embankments, which have been constructed in the past; the desirability of continuing to rely on the existing embankments; and the potential for soft adaptation strategies to address the problem in the future.

The analysis of the performance of the existing embankments showed that, on balance, their benefits have not outweighed the costs of constructing and maintaining them. Such is the case because they have created significant negative externalities that may not have been anticipated when they were first built. The embankments run parallel to the river banks, preventing the river from flooding adjacent areas during the monsoons. However, at other times of the year, runoff from higher ground would get trapped behind the embankments, and would be unable to flow into the river. Moreover, 13 villages located on the river side of the embankments are trapped when the river rises. Those communities are likely to have the lowest incomes in the region, given the undesirability of their location.

The study projected future conditions based on four different climate scenarios. All of them suggest more extreme rainfall patterns. Drought will become more likely most of the year, while the monsoon rains will slightly increase. Using a DEM, they projected flood conditions in the future, both with the existing embankments, and if they were removed.

The CBA considered both hard adaptations — maintaining the embankments — and an array of soft ones that included: raising the levels of homes and other structures; raising the levels of communal toilets and drinking water supplies so they would not mix with flood water; establishing community-based flood early warning systems and systems for removing key drainage bottlenecks; constructing community shelters and grain banks; and purchasing community boats. With many caveats about the available data, the authors report that, although new embankments would not be cost effective, maintaining the existing ones does continue to make more sense than letting them erode or destroying them. Beyond that, however, soft adaptations that build resilience to the problems rather than attempting to block them altogether are more effective – in large measure because they can evolve in response to the changing conditions and do not require large upfront capital investments. However, unlike a physical structure that could be maintained by a few people hired for the purpose, the soft adaptations require constant attention and ongoing community involvement. The analysts also find that changes in the community over the past 20 years will make some of the soft adaptations more effective than in the past. The widespread use of cellphones in particular makes early warning relatively easy and reduces costs imposed by the floods.

This assessment considers a set of soft adaptations that are linked to each other. The assessment identifies a group of losses (housing, other assets, seeds, grains) and a set of interventions; it flags which interventions contribute to reducing each loss. The analysts recognized that the interventions combine to affect the losses — for example, the community organization that is needed to clear drainage points would also help in operating an early warning system — but their approach to quantifying these links in their model is limited. They analyzed the costs and benefits of each adaptation separately. They then summed the benefits by type of loss to which they contribute, but stopped summing once the loss had been completely eliminated. This is a simple way to deal with interrelated adaptations, but it is not exact since it does not take into account the ways in which one expenditure may contribute to reducing several types of climate change harm.

6.4 DISCRETE VERSUS INTEGRATED ADAPTATION

Adaptation activities can be discrete projects or they can be integrated into development projects aimed at other objectives. This paper has focused on discrete adaptation activities, but it is important to consider how these assessment techniques can be used when adaptation is integrated into other projects. Broadly speaking, integrated adaptation can take two different forms. In some sectors, any development project must take climate change into account in order to make sure that the project activities will be viable as the climate changes. Such is certainly the case of projects that involve constructing long-lived infrastructure such as roads or dams. It also is the case with agriculture projects focused on introducing new crops that might increase farmers' incomes. In such cases the climate change adaptation is built into the project, and its assessment will be built into the assessment of the project as a whole. Thus when the road is designed, it will be designed to withstand expected weather conditions over its expected lifespan; those expected weather conditions will include predicted climate change. As with pre-climate change road design, an assessment will be made of how resilient it needs to be to expected storms, and a CBA may be conducted to decide which level of resilience is affordable and appropriate. The analytical process will be the same as for the pre-climate change road; it is the expected storms that will change, and with it perhaps the resulting choice of road design. Similarly, in designing an agriculture project that introduces new crops, the crops to be introduced will have to be ones that will grow under expected climate conditions, and any prior assessment of the project plans will have to consider how they will work out as growing conditions change. The climate change concerns will not be analyzed separately from the project as a whole; they will be integrated into the analysis of the overall project.

In other integrated projects, adaptation may be less closely tied to the primary project purpose. A project to support agricultural extension services might include a component on educating extension agents and the farmers they serve about climate change, if climate change is likely to be a significant issue in the sector. A community-based natural resources management (CBNRM) project might work with the community on anticipating the need to adapt to climate change at the same time that it helps them identify community development priorities; access funds to invest in community projects; and learn reading, writing, and arithmetic so they can manage their development project. In such cases, depending on the nature of the adaptation activity, it may often be possible to assess it separately from the rest of the project, if the costs and benefits of that component can be differentiated from those of the rest of the project. This approach may be analogous to analyzing one adaptation activity within a portfolio separately from the other activities in the portfolio. If the success of one activity does not depend on sharing funding with another activity, then they can be assessed separately; otherwise this may be difficult.

However, it would be worth asking why a separate assessment should be done. The assessment of a proposed development project does not typically involve separate assessments of the different activities within it. In the CBNRM example, we would not assess the community-building impacts of deciding together on development priorities separately from the broader educational impacts of teaching people to read and write so that they can manage their community project. This kind of project integrates a variety of objectives and a variety of activities; deciding about each of them separately would probably weaken the whole project. If the adaptation funding comes from a separate source from the rest of the project (as is sometimes the case when agencies have a climate change budget separate from their sectoral budgets), then such a separate assessment might be required for administrative reasons; but absent such obligations, this approach may not make sense.

7.0 USING THE RESULTS OF THE COST-BENEFIT ANALYSIS

The conventional rule of thumb in CBA is that if the benefits exceed the costs, or the ratio of benefits to costs is greater than one, then the activity makes sense. When the analysis is comparing a group of activities, it will rank them by benefit-cost ratio, from highest to lowest, and recommend that they be implemented from the top of the list as long as the ratio is positive and funds to pay for them are available. Although we may not expect anyone to literally rank projects by benefit-cost ratio and implement them in order, this conventional rule does emphasize the basic purpose of CBA. It lets us assess which activities will actually give us the best value for our money by having the greatest impact on the harms caused by climate change at the lowest cost. If those making adaptation decisions understand the results of the analysis, it should help them to make adaptation choices that will help solve their problems.

In practice, of course, the choice of activities is not so mechanistic, nor is it only based on monetary values. A number of considerations go into how the results of the CBA are used in making decisions, as discussed in this section.

7.1 MANAGING CLIMATE RISK

Several strategies in the use of CBA results can help decision makers to manage the uncertainty involved in choosing adaptation strategies. Some of these are rooted in a **scenario approach**. Instead of assuming a given climate picture with a single probability distribution for major hazards, analysts using this approach estimate the costs and benefits of each of set of adaptation activities under several different climate scenarios. With those assessments in hand, decision makers can choose among adaptation options in several ways.

They may prefer to limit themselves to adaptation activities for which benefits exceed costs under all climate scenarios. These are referred to as **no-regrets strategies** because they make economic sense irrespective of how climate change affects the place in question. Limiting the choice to no-regrets strategies is a highly risk-averse approach. It reduces or eliminates the chance of investing in an adaptation activity that turns out to have been unnecessary and would have wasted resources that could have gone to more productive activities. Thus it avoids the losses that would result if climate change turns out to be worse than predicted. However, this approach builds in losses that come from overinvesting in climate protection and losing the opportunity to use the funds for something else. As with most potentially risky investments, the higher the level of risk one is willing to accept, the higher the potential payoff; but if the choice was wrong, the chance of loss is higher.

A related approach to risk management is rooted in **portfolio theory** (Watkiss et al., 2009). Based on principles of risk minimization in financial management, portfolio theory suggests that instead of individually assessing and choosing among adaptation strategies, public officials should seek to maximize the net benefits from a portfolio of activities, ensuring that some activities in the portfolio will be effective under each climate conditions. This approach lowers the risk from what the community would confront if they went with a single prediction of the impacts of climate change. Unlike the no-regrets strategy, it does not require that each adaptation be effective under all climate scenarios; it only requires that some of the adaptations in the portfolio be effective under each scenario considered. Like the no-regrets strategy, it avoids the need to assess the probability of each climate scenario since it does not select a single scenario and plan only for that level of climate change.

Another somewhat different strategy for dealing with uncertainty is through so-called **real options**, similar to **flexible adaptation pathways**. The term "real option" comes from financial options, notably calls, when an investor buys the right to purchase a given financial instrument at today's price at any time up to a specified date in the future. If the price of the instrument rises, the investor exercises the call, buying the instrument at the contracted price and immediately reselling it at the market price. In the adaptation arena, a "real option" can refer to guaranteeing the option to purchase a piece of real property should the climate evolve in such a way that makes it useful. It can also refer, more abstractly, to designing a long-lived hard adaptation so that it meets currently anticipated needs in the short run, but can be modified in the future depending on how the climate evolves. This approach allows the decision maker to postpone some investment decisions until the future, when more information will be available about how the climate evolves. The cost of keeping the option open, purchasing land now that might be used for construction later if needed (but could also be resold), or designing a physical structure so that it can be expanded later, is much lower than the cost of building now for possible future needs. Just as the financial investor had to pay to purchase the call, there is a cost, but it is much lower than overinvesting now to be ready in case the climate evolves in a way that makes it necessary.

Real options are a risk-reducing adaptation strategy included in the CBA, rather than a principle for making decisions based on the results of the CBA. For example, for a community that is considering hard adaptations to reduce flooding, the real options-based strategy will be added to the alternatives evaluated:

- **The risk-taker strategy**: *A low wall that could be overtopped by 50-year floods.* If climate change proceeds slowly, and the probability of a 50-year flood only rises from 2 percent to 2.1 percent over the first 20 years of the wall's life, this approach may be fine. But if climate change proceeds rapidly, and the probability of a 50-year flood rises from 2 percent to 10 percent in 20 years, the harm from climate change will be too high to be acceptable.
- **The risk-averse strategy**: *A high wall that could be overtopped by 100-year floods*. If climate change proceeds quickly, this wall will protect people living behind it. But if it proceeds slowly, resources will have been invested here that could have been better used elsewhere.
- **The real option strategy**: *A low wall designed so that it can rapidly be raised if the climate changes rapidly* will cost somewhat more than the first low wall, but much less than the high wall. If in five or 10 years the climate does seem to be changing rapidly, the wall can be raised, exercising the option; but if it is changing slowly, there will be no need to exercise the option. This strategy will ensure that the investment in a high wall will only be made if it is actually needed; and in the short run, funds will not be tied up in constructing and maintaining an overdesigned structure.

7.2 EQUITY

CBA is not well suited to analyzing the impacts of activities on different income groups. The basic approach is to sum all of the benefits of the activity and all of the costs, and compare them. This does not provide any way to differentiate who receives how much of the benefits, and who pays how much of the costs. Some of the valuation tools we have discussed could make it possible to disaggregate the analysis, essentially carrying out a separate estimation of costs and benefits for distinct income classes within the population. This could allow us to develop decision criteria taking equity into account. Based on this information, one approach to choosing could be to weight the costs and benefits accruing to different income groups differently, and sum the weighted figures in order to arrive at an overall assessment. This approach, however, could have some activities turn out positive when in fact their unweighted costs exceed their benefits. Alternately, we could first screen out the activities whose unweighted costs exceed their benefits, and we could select from the remaining ones specifically based on impacts on low income groups rather than based on the overall benefit-cost ratio. However, disaggregating the analysis by income class would require a level of detail in the data that is not likely to be available in many developing countries.

7.3 CBA AS A DECISION PROCESS OR AS ONE OF MANY DECISION CRITERIA

Although this paper has focused on economic analysis of adaptation options, it is clear that this approach is too narrow to be the sole basis for decision making. Some impacts of climate change, notably health and biodiversity, do not lend themselves to valuation in monetary terms. Mortality and morbidity can be quantified in DALYs, and the choices made based on cost-effective analysis. "Pure" biodiversity and its core role in natural systems rather than the services it provides to humans is difficult to quantify at all, so cost-effectiveness analysis may be no more useful than CBA. Moreover, as discussed in the previous section, it can be difficult to quantify or assign monetary value to the benefits of many soft adaptations, making it difficult to evaluate them. See Box 8.

BOX 8. USING REAL OPTIONS ANALYSIS TO CHOOSE AMONG HOUSES IN VIETNAM

Dobes (2010) uses real options to consider housing choices in Vietnam's flood-prone Mekong Delta. Rural households in the area have always built their homes on stilts; the rule of thumb being to raise the house to one meter above the previous highest flood in the region ("one meter freeboard"). With climate change, however, households are confronted with a choice: Do they build new homes with much more than one meter of freeboard? And if so, how much? Or do they run the risk of being flooded if they stick with previous practices?

Dobes takes a real options approach to consider the choice between two new house designs. One offers flexibility in case of floods. In the short run, the floor can be raised; in the longer run, the whole house can be moved. The other is fixed in height and in place. With one meter freeboard, it costs less than the flexible house, but would have to be replaced if floods consistently reach unexpected heights. It could also be constructed with much greater freeboard, say five meters, which is far more than needed but could guarantee protection in the case of any flood level. Dobes estimates the net present value of each house as:

NPV = PV (benefits – costs) + OV + upfront house purchase price

Where: PV is the present value of the benefits and costs of each house over time
Benefits stem from avoided flooding; these will be low if the fixed house floods
Costs of the house are routine maintenance
OV is the willingness to pay for the option of raising the floor in the flexible house

The only values he actually knows are the purchase prices of the two houses: $1,700 for the flexible house and $1,130 for the fixed house; presumably at this price, the fixed house is on low rather than high stilts. This is not enough information to permit calculation of the value of the real option (i.e., how much flexibility contributes to the value of that house); but it does let us see how the options would be compared with better data. To simplify the framework, suppose costs are the same for all houses. Suppose, further, that the cost of modifying the flexible house in case of high floods is $500. The table below shows two cost comparisons under two price scenarios for the high-stilt fixed house, $2,100 and $2,500.

		Additional Costs		
	Purchase	Low Floods	High Floods	Total
Low-stilt fixed	1,130	0	1,130	2,260
High-stilt fixed	2,100	0	0	2,100
Flexible	1,700	0	500	2,200
Low-stilt fixed	1,130	0	1,130	2,260
High-stilt fixed	2,500	0	0	2,500
Flexible	1,700	0	500	2,200

If the floods don't rise, the low-stilt fixed house is the best option; however, this approach means taking the risk of having to replace the house if floods do rise. In the first scenario, the risk-averse homebuyer would probably go with the flexible house; for an additional $100 over the high-stilt house, he might get to save the $500 for house modification, and in any case those expenses will be postponed. In the second scenario, the risk-averse homebuyer would also go with the flexible house, since even with modification costs it is cheaper than the high-stilt house. In both cases, the risk-taking homebuyer would stay with the low-stilt house; however, if that house were more expensive, those buyers would begin to shift to the other options given that if the high floods did occur and the cost rose, the differential between the price of the low-stilt house and the other option would decrease. Clearly more data — including the probability of the floods rising — would be needed in order to actually assess whether a real option actually makes more sense than a fixed structure. But this example shows how this can be a useful strategy if the prices are right.

Additionally, CBA does not factor in many cultural and social values that do not lend themselves to economic analysis. Economics as a field may assume that all humans are rational profit-maximizers who make decisions based on financial self-interest; but even economists, being humans themselves, are quite aware that this assumption only partially describes how people actually behave. For this reason, many studies of CBA for adaptation recommend that the benefit-cost ratios generated by the tool be only one among many inputs into a broader decision process.

When a relatively small community is making decisions, they may engage all of the stakeholders in working through adaptation options and understanding both their economic costs and benefits and the other factors that will go into choosing among them. Some kinds of CBA tools may actually be more suited to this kind of process than others. Small communities are not likely to have the resources, in skills or data, to carry out highly complex modeling work. Moreover, when stakeholder engagement is an important part of the decision process, communities may do better to stick with fairly simple analytical tools that participants are likely to understand, rather than using sophisticated methods that will be a black box to those making decisions.

Some groups using CBA to assess adaptation strategies recommend that it be used primarily to structure a community decision process, rather than focusing on the actual statistical results (e.g., Khan et al., 2012). In this approach, the community works together to carry out each step in the analysis: thinking through how climate change is expected to affect them, identifying who will be harmed or benefited, brainstorming possible strategies to reduce that harm, considering all of the economic and non-economic benefits and costs of each of those strategies, and then choosing among them based on a wide range of criteria of which the benefit-cost ratio is only one.

One variant on this approach has been termed **qualitative cost-benefit analysis** (see Box 9). It has been used to facilitate adaptation decision making when the scale of the decisions being made is too small to justify a full-blown quantitative CBA. The Institute for Social and Environmental Transition (ISET) has developed a process for carrying out this analysis. They call it "shared learning dialogues," which they have applied in a number of countries (Khan et al., 2012). This is a community-based process, led by trained facilitators rather than experts in CBA. It involves a significant effort to bring in all members of the community, especially those likely to be most vulnerable to climate change. The facilitators provide information about the likely impacts of climate change in the area, and community members brainstorm about how they will be affected and how they could best increase their resilience. Instead of carrying out an empirical analysis of the costs and benefits of the options they identify, they work together to assign scores to each option reflecting their best assessment of the costs and benefits as well as other criteria for assessing the options. This allows them to factor in distributional impacts, since they know who will be affected and have a sense of relative income levels in their community. Based on this process, they choose the adaptation options that they feel best meet their needs. Though termed qualitative "cost-benefit" analysis, this approach is really close to being a community-based multi-criteria analysis.[11]

[11] Multi-criteria analysis is a method for rigorous analysis of options through which criteria are identified according to which it is to be assessed, and the analysts assign scores to each option for each criterion. The scores may be summed, averaged, or combined into an index in other more complex ways. This approach makes it possible to combine economic and non-economic criteria into a single analytical framework, and to combine criteria that would otherwise each require different metrics for measurement (e.g., money for some, DALYs for others). Multi-criteria analysis is the subject of another study being carried out through the ARCC project.

BOX 9: QUALITATIVE COST-BENEFIT ANALYSIS IN THE POKHRA DISTRICT OF NEPAL

Nepal is among the countries most at risk from climate change worldwide. Consequently, in addition to preparing a National Adaptation Plan of Action, the country has also encouraged the preparation of Local Adaptation Plans of Action through which rural communities could identify the risks they face and the adaptations that make the most sense for them.

The Li-Bird community organization in Pokhra District was one group to engage in this process, as described in Khan et al. (2012). Members of the community worked with a facilitator to evaluate the economic, environmental, and social costs and benefits of a group of adaptation strategies aimed at protecting their agricultural systems in the face of climate change. The facilitator steered their discussions to encourage them to consider not only the direct outcomes of the different strategies, but also their long-run environmental and social costs and benefits, including how they affected specific gender or income groups within the community. The facilitator also had to ensure that the scoring, on a scale of 1-5, was consistently applied by all participants in the process. This process resulted in the scores shown in the table below.

	Cost Scores				Benefit Scores				B/C
	Envtl	Econ	Social	Total	Envtl	Econ	Social	Total	
Minimum tillage	0	2	1	3	5	4	4	13	4.33
Plant degraded and eroded land	0	3	1	4	5	5	5	15	3.75
Construct check-dams	1	5	3	8*	5	4	4	13	1.62
Protect water sources	0	4	3	7	5	5	5	15	2.14
	* Calculation error in source								
Source: Khan et al., 2012, p. 66.									

The economic scores in this approach would be proxies for the direct financial costs and benefits of each option. The environmental and social scores would capture externalities, opportunity costs, and perhaps indirect costs and benefits, although the paper does not provide full detail on what is included. The authors explain that it was quite easy for the participants to come up with the economic scores, but that they had much more trouble with the environmental and social scores. The authors also feel that the economic scores would have accurately reflected actual monetary costs and benefits, had a quantitative CBA been possible. They don't explain why they believe this, however, and of course we don't have "real" data for comparison.

Beyond the quality of the results, by involving the whole community and pushing them to discuss both economic and non-economic implications of the different adaptation options, this process led to community buy-in to the decisions that might not have occurred if an outside expert had carried out a more sophisticated analysis. Moreover, it only took a day of work for each participant; this level of effort may be regarded as the "appropriate technology" of CBA for those working at a community level.

8.0 CONCLUSIONS

CBA is an essential tool in the assessment of adaptation activities. Wherever it can be used, it sheds valuable light on the best ways to allocate limited resources so as to strengthen resilience to the harms that will be caused by climate change in the decades to come.

The way in which any CBA is carried out will be determined to a significant extent by the resources available for the study. Rigorous CBA can require access to extensive empirical data. It can require a high level of technical skill on the part of the analysts. It can require a fairly long time to carry out the analysis. If the resource commitment is high, then funds can be put into collecting primary data and hiring highly technical analysts for a long period to conduct a CBA. However, if resources are more limited, compromises will have to be made in the type of analysis carried out; the CBA will have to rely on readily available data, on the results of analytical work already carried out by other experts, and on the skills of those already working on the project rather than specialized consultants. The results of such a study will have a higher margin of error, and therefore may be less useful in making choices among adaptation options. This limitation does not invalidate such studies; a modest study with a low budget can often be almost as useful as a more extensive one that costs 10 times as much. Although we can't actually quantify the relative utility of different kinds of CBAs, the trade-offs between resources required and contribution of the results to informed choice among adaptation options should be given some thought in designing the analysis.

CBA has its limits, however. It is not well-suited to analyzing the equity of adaptation strategies because it compares the total benefits of each activity with its total costs without disaggregating those benefits and costs by income class, gender, ethnic group, or other important social categories. It may be possible to do this kind of disaggregation in some cases, when the data are sufficiently detailed and the analytical methods permit it; but these cases will be rare.

Beyond CBA, economic analysis in general has its limits. It is a key input into adaptation decision making, but it should never be the only input. Many of the important criteria for choosing adaptation options are not economic; they are social, cultural, environmental, ethical, or political. The analyses discussed in this report should be regarded as one input into the decision, considered along with, and weighed against, other things we care profoundly about, like how we use our time, how healthy we are, what benefits others in our community or country, what makes us happy, or what we consider morally right. This broad range of decision criteria may be integrated into a broader analysis using tools like multi-criteria analysis.

In addition, the process of carrying out CBA can offer a useful way to structure public participation in the choice of adaptation strategies. As a process tool, CBA can create a sense of ownership of the choice of adaptation activities, which may contribute to ensuring that they will be effectively implemented with strong community engagement. When CBA is used in this way, the resulting commitment to adaptation may be at least as valuable an outcome of the process as the benefit-cost ratio that is its direct result.

CBA can be carried out in many different ways, using different tools to do the analyses required to estimate costs and benefits. The choice among these tools depends on several key factors:

- What is most suitable for the sector or issue targeted by the adaptation;
- The availability of reliable data on the right issues, at the right scale, with sufficiently long time series;

- The resources available to carry out the analysis: how much time it can take, how much and what kind of technical assistance can be hired, and whether primary data can be collected; and
- Whether community participation is an important part of the choice of adaptation strategies; if it is, simpler analysis tools may be more effective than complex modeling.

CBA is easiest for hard adaptations, stand-alone adaptations, and adaptations that have clearly identified, quantifiable outputs. Where the outputs can be quantified but are difficult to value in monetary terms, cost effectiveness analysis may be a more useful approach. Where outputs cannot easily be quantified, tools such as multi-criteria analysis, which score project performance rather than quantifying it, may be more helpful than CBA. Such non-economic tools are also appropriate for integrating economic, social, cultural, and ethical evaluation criteria in a single decision process.

Many activities focus on capacity building, particularly in the areas of data availability and use for climate change work, governance, and identification and dissemination of effective adaptation strategies. CBA is not a good tool for assessing this kind of adaptation activity because it is very difficult to quantify the output of capacity building work, and even more difficult to put a monetary value on it. To assess these activities, multi-criteria assessment or other non-economic tools may be more appropriate. On the other hand, capacity building sometimes involves teaching others how to carry out CBA of adaptation strategies. This work will be quite useful; moreover, this paper provides the groundwork for launching that work and developing training materials to carry it forward.

9.0 SOURCES

Agrawala, S., and S. Fankhauser. (eds.) (2008). *Economic Aspects of Adaptation to Climate Change: Costs, Benefits, and Policy Instruments.* Organization for Economic Cooperation and Development: Paris. Available at: www.cambioglobalyclimatico.es/sites/default/files/publicaciones/10-_dc1082.pdf

Bergman, L., and M. Henrekson. (2003). CGE Modeling of Environmental Policy and Resource Management. Available at: users.ictp.it/~eee/workshops/smr1533/Bergman - Handbook-1.doc

Dixit, A. (2012). From Assessment to Implementation: Approaches for Adaptation Options Analysis. June. World Resources Institute: Washington, D.C.

Dobes, L. (2010). Notes on applying 'real options' to climate change adaptation measures, with examples from Vietnam. CCEP Working Paper 7.10. Centre for Climate Economics and Policy, Crawford School of Economics and Government. Australian National University: Canberra. Available at: http://www.economicsclimatechange.com/2011/ 01/notes-on-applying-real-options-to.html

Economics of Climate Adaptation Working Group (ECAWG). (2009). *Shaping Climate-Resilient Development: a framework for decision-making*.
Available at: http://www.unep.org/climatechange/adaptation/EconomicsandFinance/ Economicsofclimatechangeadaptation/tabid/29586/Default.aspx

Environment Canada. (n.d.). Environmental Valuation Reference Inventory. Available at: Available at: https://www.evri.ca/Global/Splash.aspx

Global Climate Forum. (n.d.) DIVA Model. Available at: http://www.diva-model.net

Hanson, S., R. Nicholls, S. Hallegatte, and J. Corfee-Morlot. (2010). *The effects of climate mitigation on the exposure of worlds large port cities to extreme coastal water levels.* Work Stream 2. Report 7 of the AVOID Programme (AV/WS2/D1/R07).
Available at: www.metoffice.gov.uk/avoid/files/resources-researchers/AVOID_WS2_ D1_07_20100128.pdf

Hecht, J., J. Kahata, and K. Vincent. (2011). Costs Imposed by Climate Change in Three Ecoregions of East Africa: Study prepared for USAID East Africa Office of Regional Economic Growth and Integration. Study conducted through the International Resources Group ENCAP Project. March. Available at: www.joyhecht.net/East Africa Climate Change/eacc.html

Hughes, G., P. Chinowsky, and K. Strzepek. (2010). *The costs of adapting to climate change for infrastructure*. Development and Climate Change Discussion Paper. No. 2. World Bank: Washington D.C. Available at: http://documents.worldbank.org/curated/en/2010/08/12779218/costs-adapting-climate-change-infrastructure

Jha, A. K., R. Bloch, and J. Lamond. (2012). *Cities and flooding: a guide to integrated urban flood risk management for the 21st century*. World Bank: Washington D.C. Available at: http://documents.worldbank.org/curated/en/2012/01/15804535/cities-flooding-guide-integrated-urban-flood-risk-management-21st-century

Jones, J.W., G. Hoogenboom, C. H. Porter, K. J. Boote, W. D. Batchelor, L. A. Hunt, P. W. Wilkens, U. Singh, A. J. Gijsman, and J. T. Ritchief. (2003). "The DSSAT cropping system model." *The European Journal of Agronomy,* 18, 235-265.
Available at: http://www.uwyo.edu/plantsciences/afri-cap-legumeadoption/_files/pdfs/dssat.pdf

Kebede, A.S. and R.J. Nicholls. (2011). Population and Assets Exposure to Coastal Flooding in Dar es Salaam (Tanzania): Vulnerability to Climate Extremes. Submitted to the Global Climate Adaptation Partnership (GCAP). Report prepared by the Tyndall Center for Climate Change Research. Southampton, Highfield: UK.
Available at: http://economics-of-cc-in-tanzania.org/images/Dar-es-Salaam_City-Analysis_Final-Report_1_.pdf.

Kebede, A.S., S. Hanson, R. J. Nicholls, and M. Mokrech. (2010). Impacts of climate change and sea-level rise: a case study of Mombasa, Kenya. Tyndall Working Paper No. 146. www.tyndall.ac.uk/sites/default/files/twp146.pdf

Khan, F., M. Moench, S. Orleans Reed, A. Dixit, S. Shrestha and K. Dixit. (2012). Understanding the Costs and Benefits of Disaster Risk Reduction Under Changing Climate Conditions: Case Study Results and Underlying Principles. March. ISET-International: Bangkok. Available at: http://i-s-e-t.org/publications

Kull, D., P. Singh, S. Chopde, S. Wajih, and The Risk to Resilience Study Team. (2008). Evaluating Costs and Benefits of Flood Reduction under Changing Climatic Conditions: Case of the Rohini River Basin, India. From Risk to Resilience Working Paper No. 4. M. Moench, E. Caspari, and A. Pokhrel (eds.). ISET-Nepal and ProVention: Kathmandu, Nepal. Available at: http://i-s-e-t.org/publications

Lange, G.-M. with S. Dasgupta, T. Thomas, S. Murray, B. Blankespoor, K. Sander, and T. Essam. (2010). *Economics of Adaptation to Climate Change – Ecosystem Services*. World Bank: Washington, D.C. Available at: climatechange.worldbank.org/content/economics-adaptation-climate-change-study-homepage

Lempert, Robert, and Nidhi Kalra. (n.d.) Managing Climate Risks in Developing Countries with Robust Decision Making. World Resources Report: Washington D.C. Available at: http://www.worldresourcesreport.org

Lempert, R.J., S.W. Popper, and S.C. Bankes. (2003). *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis*. RAND Corporation: Santa Monica, CA. Available at: www.rand.org/pubs/monograph_reports/MR1626.

Mechler, R., and the Risk to Resilience Study Team. (2008). "The Cost-Benefit Analysis Methodology, From Risk to Resilience Working Paper No. 1." M. Moench, E. Caspari,. and A. Pokhrel (eds.). ISET, ISET-Nepal and ProVention: Kathmandu, Nepal.
Available at: http://preventionweb.net/english/professional/publications/ v.php?id=8114

Mechler, R., S. Hochrainer, D. Kull, S. Chopde, P. Singh, S. Wajih, and The Risk to Resilience Study Team. (2008). Uttar Pradesh Drought Cost-Benefit Analysis. From Risk to Resilience Working Paper No. 5. Moench, M., Caspari, E. and A. Pokhrel (eds.). ISET-Nepal and ProVention: Kathmandu, Nepal. Available at:
http://preventionweb.net/english/professional/publications/v.php?id=8114

Metronomica Ltd. (2004). "Costing the impacts of climate change in the UK: Implementation report." Prepared for the United Kingdom Climate Impacts Programme.
Available at: http://www.ukcip.org.uk/costings/

Nakicenovic, N., and Rob Swart (eds.). (2000). *Special Report on Emissions Scenarios*. IPCC: Geneva, Switzerland and Cambridge University Press: UK. Available at: http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0

Nelson, G.C., M.W. Rosegrant, J. Koo, R. Robertson, T. Sulser, T. Zhu, C. Ringler, A. Palazzo, S. Msangi, M. Batka, M. Magalhaes, R. Valmonte-Santos, M. Ewing, and D. Lee. (2010). *The costs of agricultural adaptation to climate change*. Development and Climate Change Discussion Paper. No. 4. World Bank: Washington, D.C. Available at: documents.worldbank.org/curated/en/ 2010/08/12779214/costs-agricultural-adaptation-climate-change

Nicholls, R. J., S. Hanson, C. Herweijer, N. Patmore, S. Hallegatte, J. Corfee-Morlot, J. Chateau, and R. Muir-Wood. (2008). *Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates.* OECD Environment Working Papers. No. 1. OECD Publishing. doi: 10.1787/011766488208.
Available at: www.oecd-ilibrary.org/content/workingpaper/011766488208

Sedjo, R.A. (2010). *Adaptation of Forests to Climate Change.* World Bank: Washington, D.C. Available at: climatechange.worldbank.org/content/economics-adaptation-climate-change-study-homepage

Sohngen, B., R. Mendelsohn, and R. Sedjo. (2001). A global model of climate change impacts on timber markets. *J. Agr. Resour. Econ, 26*(2), 326–343.
Available at: ageconsearch.umn.edu/ bitstream/31044/1/26020326.pdf

Sumaila, U.R., and W.W.L. Cheung. (2010). *Cost of adapting fisheries to climate change. Development and Climate Change*. Discussion Paper No. 5. World Bank: Washington, D.C. Available at: documents.worldbank.org/curated/en/2010/08/12779737/cost-adapting-fisheries-climate-change

Tanser, F. T., B. Sharp., and D. le Sueur. (2003). Potential effect of climate change on malaria transmission in Africa. *The Lancet, 362* (9398), 1792-1798.
Available at: http://www.thelancet.com/journals/lancet/ article/ PIIS0140673603148982/abstract

UKCIP. (2010). *The UKCIP Adaptation Wizard.* V 3.0. UKCIP: Oxford. Available at: www.ukcip.org.uk/wizard/

UNFCCC. (n.d.). Assessing the Costs and Benefits of Adaptation Options: An Overview of Approaches. *Report of the Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change*. Available at: http://www.unfccc.int/files/adaptation/ nairobi_work_programme/knowledge_resources_and_publications/application/pdf/2011_nwp_costs_benefits_adaptation.pdf

UNFCCC. (2010). Potential costs and benefits of adaptation options: A review of existing literature. Technical paper FCCC/TP/2009/2/Rev.1 11. May. Available at: http://www.unfccc.int/documentation/documents/advanced_search/items/6911.php?priref=600005438

UNFCCC Secretariat with E. Pinto, R.C. Kay and A. Travers, CZM Pty. Ltd., Stratus Consulting Inc. (2008). Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change. February. Available at: http://www.unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_ publications/items/2674.php

van den Bergh, J.C. J.M. (2004). "Optimal climate policy is a utopia: from quantitative to qualitative cost-benefit analysis." *Ecological Economics, 48*, 385-393. Available at: ideas.repec.org/a/eee/ecolec/v48y2004i4p385-393.html

Watkiss, P., H. Hunt, and L. Horrocks. (2009). "Final Report for the Scoping Study for a National Climate Change Risk Assessment and Adaptation Economic Analysis." Defra Contract number GA0208. Metroeconomica, AEA Group, and Paul Watkiss Associates. Defra. Available at: http://randd.defra.gov.uk/Document.aspx?Document= GA0208_7996_SCO.pdf

World Bank. (2010a). *The Costs to Developing Countries of Adapting to Climate Change: New Methods and Estimates.* Consultation Draft. From the Global Report of the Economics of Adaptation to Climate Change Study. World Bank: Washington, D.C.
Available at: climatechange.worldbank.org/content/economics-adaptation-climate-change-study-homepage

World Bank. (2010b). *The Economics of Adaptation to Climate Change: Synthesis Report.* From the Global Report of the Economics of Adaptation to Climate Change Study. World Bank: Washington, D.C. Available at: climatechange.worldbank.org/content/economics-adaptation-climate-change-study-homepage

World Bank. (2013). Climate Change Projects & Programs. Available at: http://climatechange.worldbank.org/content/adaptation-guidance-notes-key-words-and-definitions

World Health Organization. (2004)). "Global Burden of Disease 2004 Update: Disability Weights for Diseases and Conditions."
Available at: www.who.int/healthinfo/global_burden_disease/GBD2004_DisabilityWeights.pdf

10.0 ANNEXES

ANNEX 1. UNFCCC COMPENDIUM

The UNFCCC has prepared a compendium of tools available for carrying out the different analyses required to estimate the impacts of climate change (UNFCCC, February 2008). It includes 140 different tools, ranging from fairly simple spreadsheets to complex modeling systems, some cutting across the impacts of climate change, and others specific to individual sectors – agriculture, water, coastal resources, health, and terrestrial vegetation. This resource is invaluable for analysts deciding how they will actually carry out a CBA on adaptation strategies. The textbox below shows the information provided about each tool.

BOX A.1. INFORMATION PROVIDED ABOUT CLIMATE CHANGE IMPACTS ANALYSIS TOOLS (UNFCCC, 2008, PP. 1-5)

Description. Explains the type of framework or tool being presented (e.g., spreadsheet, process-based model) and what type of information this tool helps the user to evaluate (e.g., monetary costs, human health risks). This area also provides a basic summary of how the tool works, including the type of data required and the processes used to evaluate these data.

Appropriate use. Describes where the framework or tool is (and is not) applicable. This information gives the user an idea of the stage at which it is appropriate to use.

Scope. Covers the fields in which the framework or tool is applicable, including geographic (i.e., whether it is specific to a particular region) and assessment characteristics (e.g., national or site-specific).

Key output. Describes the final product of the framework or tool (e.g., a model, a cost-effectiveness evaluation, an organizing framework).

Key input. Explains the information or data required to use the framework or tool.

Key tools. For frameworks, describe discrete tools that would play an important role in implementing a complete framework.

Ease of use. Describes the level of difficulty associated with implementing the framework or tool.

Training required. Describes the level of expertise and any specific skills required to use the framework or tool effectively.

Training available. Describes training to learn how to use the framework or tool effectively.

Computer requirements. Describes the computer hardware and software to use the framework or tool.

Documentation. Provides the citations for sources that describe in detail how to use the framework or tool. Generally this is a user's manual or similar document.

Applications. Briefly describes actual cases and projects where the framework or tool has been applied.

Contacts for framework/tools, documentation, technical assistance. Provides information on who to contact for further information, documentation, and technical assistance. Generally the agency or firm that developed the framework or tool, or, for several of the tools applicable to multiple sectors, someone who can provide a reference to an expert for a particular application.

Cost. Provides the monetary cost of obtaining documentation or software for the framework or tool. Where applicable, gives information on the approximate cost of implementing the framework or tool. Where the exact cost is unavailable, relative cost is used (e.g., high, medium, or low relative to other described).

References. Lists citations for documents, articles, etc., that have critically discussed use of the framework or tool.

ANNEX 2. COMPARISON OF ANALYSIS TOOLS

Tool	Type of Analysis	Applicable to What Kinds of Issues / Actions	Criteria for Choosing Options	Level of Rigor	Resource Requirements
CBA (or rate of return analysis)	Economic	Most appropriate when looking at actions that have monetary benefits to people, or that affect market activity. Can be used to assess non-marketed economic benefits such as environmental impacts.	• Benefits exceed costs (if only one action is being considered) • Ratio of total benefits to total; cost greater than 1 or highest in a list of actions ranked by benefit-cost ratio (when several actions are being compared) • The rate of return on investment in the action exceeds the cost of borrowing the capital, or average market interest rates	Relatively rigorous if the data are good and enough time is available for the study. Rigor and reliability of results decrease with time and data availability. However, use of more complex models does not necessarily mean the results are more reliable, although they do require more skill and time.	Depends on the tools used for identifying harm and assigning monetary values, on the level of detail desired, on the availability of data, on the time available, and so on. For thorough empirical analyses or complex modeling, resource requirements can be very high.
Cost effective-ness analysis	Economic plus other issues that can readily be quantified	Can be used to assess issues for which benefits can be quantified but expressing them in monetary terms is not appropriate or possible.	Choose the action that achieves the most of the desired outcome per dollar of cost.	Relatively rigorous; potentially more so than CBA because there is no need to put monetary values on the outcomes.	Similar to CBA, but somewhat less resource-heavy; it is not necessary to put monetary values on outcomes.

Tool	Type of Analysis	Applicable to What Kinds of Issues / Actions	Criteria for Choosing Options	Level of Rigor	Resource Requirements
Multi-criteria analysis (or "qualita-tive CBA")	Includes economic and non-economic elements	Can be used for any issue for which stakeholders can identify issues and qualitatively score the performance of the proposed action with respect to that issue.	Sum or average the scores of each action along each criterion; select the action(s) with the highest scores.	Less rigorous than quantitative analysis. Level of rigor depends to a significant degree on how consistent the analysts are in their scoring; if some tend to score everything higher or lower than others, then the results will not be meaningful.	Modest; less data, modeling, and technical skill required.

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