DEVELOPMENT AND CLIMATE CHANGE

Economic Evaluation of Climate Change Adaptation Projects

Approaches for the Agricultural Sector and Beyond

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Economic Evaluation of Climate Change Adaptation Projects

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ACRONYMS

GEF	Global Environment Facility
GHG	greenhouse gas
MCDA	multi-criteria decision analysis
NPV	net present value
RDM	robust decision making

EXECUTIVE SUMMARY

This paper identifies key challenges and solutions for carrying out project-level economic analysis of adaptation to climate change, both stand-alone and integrated into broader development projects. Very few projects addressing adaptation thus far have been subject to in-depth and rigorous economic analysis for a variety of reasons, including a lack of guidance on how to deal with assessments of the impacts of climate change, as well as with estimating costs and benefits of adaptation under uncertainty. Our focus is on the agricultural sector, where the impacts of climate change have the potential to disrupt the livelihoods of rural populations in many regions and where adaptation must be given urgent consideration. Nevertheless, some of the approaches discussed are suitable to projects in other sectors as well.

Over the next few decades, climate change impacts on agriculture are likely to be felt due to greater climate variability, and increased frequency and intensity of extreme events, as well as from changes in average climatic conditions. Individuals, communities and institutions often make strengthening shorter-term responses to current climate variability a priority. Nevertheless, potential future climate change trends must be taken into account when development outcomes depend on how the climate will change over the next few decades. For example, the design of a new irrigation system calls for consideration of the expected water availability during the lifetime of the project; and water availability will be influenced by, e.g., melting of glaciers threatening to compromise water availability in entire watersheds in the Andean region. Adaptation needs to deal with the medium- to long- term changes in overall climatic conditions, as well as changes in the variability of climate conditions.

The main challenges faced in carrying out project-level economic evaluations are briefly discussed below:

1. Many, if not most, of the needed investments for adaptation, especially in the agricultural sector, will also bring benefits irrespective of how much the climate changes. First, adaptation investments could increase resilience to current climate variability, while preparing for a future increase in variability due to climate change. Moreover, many responses will provide benefits beyond managing climate

risks (e.g., improving water-use efficiency in areas that are already water-scarce due to non-climatic pressures, such as increased water demand from different sectors). On the other side of the spectrum, some responses largely provide benefits only in the context of climate change risks, such as infrastructure projects (e.g., dams and dikes) that proactively respond to projected changes in factors such as runoff and sea level rise. The latter must explicitly factor the uncertainty of climate change, as well as the costs and benefits of adaptation, into the evaluation.

2. Development projects focus on public investments in adaptation. Planned adaptation—involving action by a local, regional and/or national government to provide needed public goods and incentives to the private sector to fit the new conditions—is therefore the focus of this paper. Nevertheless, autonomous adaptation — involving actions by farmers, communities and others in response to the threats of climate change perceived by them, based on a set of available technology and management options—must be taken into account in defining the "baseline" or "without-project" scenario. Moreover, in project evaluation, it is important to consider how planned adaptation may influence the private sector's capacity to undertake autonomous adaptation.

3. Evaluating the economic benefits of hard investments is relatively straightforward (although, in practice, it is not trivial) because a direct relationship can be constructed between inputs provided by the physical investment (i.e., water supply from a dam) and production output. Soft adaptation, on the other hand, is more complicated because the benefits, to a great extent, must be inferred from resulting changes in private sector behaviors and prices.

4. Decision makers have a choice about when to invest, as well as how much and in what forms. Where investment has high co-benefits in reducing a current adaptation deficit, the argument for more rapid investment is strengthened. More generally, however, deciding how much to adapt now versus waiting to do more after gaining additional information on the impacts of climate change and the options for ameliorating those impacts is not an easy decision given the uncertainties discussed above.

5. The choice of discount rate for evaluating future benefits and costs is often controversial in many other contexts, as well as in adaptation. Debates exist on the proper rates of return for evaluating projects given uncertainties, distortions from taxation and incorrect market prices, and incomplete or poorly functioning capital markets. A more particular concern in evaluating adaptation investments with long time horizons (e.g., 50–100 years) is how to value the long-term benefits. One common but ad hoc approach is sensitivity analysis using a lower discount rate to see how sensitive the project evaluation might be to benefits accruing only in the more distant future. Other approaches that try to assess the relative benefit of a project in reducing long-term uncertainty for an affected population should be considered, even if the valuation of such benefits can be undertaken only heuristically.

6. For a stand-alone adaptation project, both benefits and costs can be assessed relative to a no-project alternative. For a project with adaptation components undertaken within a broader set of activities, the comparison would be made relative to a business-as-usual project without adaptation components. In either case, but especially in the latter case, there is an inherent subjectivity and need for

expert judgment in defining the hypothetical alternative as a basis for comparison.

The problem of economically evaluating adaptation to climate change at the project level can be disaggregated into two distinct subproblems, namely:

a. Evaluating the potential impacts that climate change could have on agricultural productivity in the project area, assuming only autonomous adaptation.

b. Evaluating costs and benefits of possible planned adaptations, including the implications of uncertainty with respect to the choice of specific adaptation options.

These assessment stages are common to the evaluation of adaptation in any sector. The specific approaches and methodologies used to deal with each subproblem, on the other hand, can be different, depending on the sector and the specific project's characteristics. Possible methodologies for addressing each subproblem are briefly summarized below.

For the evaluation of climate change impacts on agriculture, two approaches in particular — the agronomic (or crop) models and the Ricardian (or hedonic) models — have become the most widely used in applications to country studies and projects dealing with climate change impacts and adaptation in agriculture. Agronomic models are biophysical representations of crop production simulating the relevant soil-plant-atmospheric components that determine plant growth and yield. They can be used to assess the impacts of climate change on agricultural productivity, as well as to investigate the potential effects of different adaptation options. The Ricardian method is based on the idea that the long-term productivity of land is reflected in the land's asset value. The impacts of different influences on land value, including climatic differences, are econometrically estimated using cross-sectional data. An important characteristic of this methodology is that the findings on longer-term climate change impacts are net of whatever autonomous adaptation responses to climate change individual farmers are able to make over the long term. Both approaches have specific strengths and weaknesses that need to be carefully considered when choosing which method to use in project evaluation.

The literature and practice in the disaster risk reduction field suggest another method for estimating expected economic losses due to climate change, as well as economic benefits of adaptation measures. This method was developed for application to natural disasters and, hence, is immediately applicable to impacts of climatic extremes (i.e., floods), although it may be possible to adapt the approach to evaluate other impacts of climate change.

The challenges in evaluating costs and benefits of hard and soft adaptation investments are similar to challenges in evaluating such investments in other types of development projects. For example, the approaches used in the past for estimating ex-ante the economic benefits of agricultural innovations can be applied to some soft adaptations. As for adaptation costs, different methods can be applied. One approach consists of piggybacking the costs of adaptation measures from an in-depth analysis of documentation of past projects that financed the same types of interventions, which would be needed for adaptation purposes (i.e., irrigation, agricultural extension, flood protection, etc.). Another possible approach is based on the solicitation of information directly from the local communities that are vulnerable to climatic risks and that take adaptation-relevant decisions.

In the case of no-regret adaptation investments and broader development projects that fully integrate adaptation into their design, isolating the costs and benefits of the adaptation component might not be feasible, as such decisions are also simultaneously conditioned by a whole range of other factors. While it might be possible in principle to consider a hypothetical alternative project designed with less adaptation integrated into it, such an effort would have little meaning and it will be more valuable to compare alternative project designs per se. For stand-alone adaptation projects or projects with a distinct adaptation component included, additionality of costs and benefits of adaptation may be useful to estimate in some cases. In particular, this can be important when there are alternative projects or component designs with different benefits and costs that can then be compared. One can also attempt to indirectly identify the costs of an adaptation activity linked to an existing development project through a "gap analysis" to pin down which additional investments are needed in order to increase its resilience to climate change by a certain degree.

The presence of co-benefits in adaptation projects is particularly important in the economic evaluation if they otherwise would not be reflected in the project appraisal. This would typically be the case if the co-benefits have the nature of public goods. For example, where investment in improved water management for adaptation in agriculture also conveys benefits for other categories of users (e.g., municipalities), estimates of these benefits can be included and strengthen the overall case for the project. These co-benefits can, at least in some cases, be quantified and would increase the overall economic attractiveness of the adaptation investments.

Alternatives to economic approaches for project evaluation exist, which may allow bypassing some of the specific challenges of an economic evaluation. Often, decision makers need or want to evaluate alternatives across a range of different and potentially incommensurate criteria. This is especially true in the context of agriculture and climate change where an adaptation project can help reduce the negative effects of climate change on a number of social and environmental, as well as economic, indicators. There also may be many instances, as already noted, when information on the monetary value of potential benefits or their likelihood of being realized is scarce and significant amounts of informed judgment must be substituted. In such cases, multi-criteria decision aiding approaches can be useful.

Economic evaluation with uncertainty usually takes the form of considering certain scenarios judged to have various degrees of likelihood. More sophisticated extensions of this approach postulate more explicit probability distributions for key factors. For some adaptation initiatives, especially when a main focus of concern is with the impacts from climatic extremes, it may be possible to economically evaluate how the project reduces the risks and expected monetary losses associated with an uncertain adverse agricultural impact.

Another possible approach is "real option analysis," which reflects the state of the art in economic evaluation under uncertainty but, thus far, remains difficult to apply in concrete cases. Real option analysis is based on the idea that some real investment projects can be evaluated as a set of compound options. For example, a water management project may help a community preserve the option of remaining in place rather than migrating if future climate change makes local livelihoods infeasible. Evaluating a project through this approach can be considered a new form of risk analysis, where risk is identified both positively, as the contingent wealth of opportunities created by the project, and as a cost, in terms of contingent liabilities the project may generate.

Finally, robust decision making (RDM) can provide an alternative quantitative decision analytic method that avoids subjective probability assessments and scenario predictions. RDM creates hundreds or thousands of plausible futures, in the judgment of the analyst, that are then used to systematically evaluate the performance of alternative actions. This approach facilitates identifying the set of conditions under which any particular alternative adaptation performs well or poorly, according to various evaluation criteria based on the decision maker's judgment. The decision maker can identify "robust" alternatives that, compared to other alternatives, perform reasonably well across a wide range of plausible futures.

Although time, budget and data limitations constitute obvious constraints in using the methods discussed, a good reason for investing in more in-depth economic evaluation of adaptation is that it can be very useful to inform project design (i.e., to select the crops most suitable to the local climate conditions, or to design project components that are likely to maximize benefits for local communities according to their own judgment). Moreover, despite the complexity of these approaches, options exist for employing simplified versions of some methodologies for project-level analysis. A series of steps for carrying out the economic analysis of an adaptation project, as well as a summary table of the methods discussed, can be useful tools for project teams.

I. INTRODUCTION

SCOPE AND CONCEPTS UNDERLYING THIS PAPER

The economics of adaptation has become a hot topic over the past few years, since the adverse impacts of climate change are raising important concerns about the future livelihoods of many people around the world. In the very near term, vulnerable communities will need to accelerate adaptation in order to mitigate the additional burdens of climate change. This is especially important in the context of agriculture, given the critical role of that sector in the livelihoods of populations throughout the developing world.

At the same time, investments in adaptation compete with other development priorities. Economic evaluation of adaptation options can provide decision makers with important information for evaluating alternative uses of scarce resources, as well as on when and how to make adaptation investments. Unfortunately, very few adaptation projects or project components thus far have been subject to in-depth and rigorous economic analysis that would contribute to weighing these trade-offs.

This paper identifies key challenges and solutions for carrying out economic analyses of adaptation projects and adaptation components within broader development projects. While our focus is on the agricultural sector, we also highlight some general approaches that are suitable to projects in other sectors as well. We concentrate on assessing adaptation at the level of specific projects, as opposed to sector-level or economy-wide assessments of adaptation potential encountered in the research and policy literatures (IPCC 2007 provides a comprehensive review of the climate change impacts and adaptation literature, including for agriculture).

For our purposes, adaptation projects are activities undertaken to ameliorate anticipated or actual losses in output and/or increases in cost of agricultural production as a consequence of climate change. Our particular emphasis here is on anticipatory adaptation, though the same basic concepts can also be applied to coping measures taken after adverse impacts are realized. The climate change drivers of the adverse impacts on output or cost include both changes in longer-term conditions (average temperature, rainfall) and increased variability of climatic conditions. This scope does not include investments to raise productivity under existing climatic conditions or to increase resilience to existing climatic variability, though in practice many of the potential activities will be the same (see also *Box 1*).[1]

We focus on economic analysis as a means for assessing the benefits and costs of investments in adaptation, as distinct from financial analysis of "additionality" in adaptation costs *vis a vis* "business as usual," e.g., for accessing dedicated adaptation financing sources. Still, we offer basic suggestions on how to approach additionality of adaptation costs and benefits.

The emphasis on assessing benefits and costs in project evaluation may invoke a perception of a narrowly focused economic analysis of aggregated net economic benefits over time. In principle, however, the ideas we are addressing can be applied more broadly (see also Heltberg and others 2009). Thinking of adaptation benefits in the context of reduced *vulnerability*, benefits can be enumerated in several ways—reduced food insecurity, greater capacity to maintain diversified assets, less stress on social relationships, reduced dread—not all of which reduce so readily into monetary equivalents. Benefits can also be assessed in terms of mitigating adverse distributional impacts of climate change. That said, we imagine that the most immediate application of the ideas discussed would be in more traditional economic analyses, which also include "satellite assessments" of other indicators.

We are concerned here with adaptation initiatives whose outcomes have the attributes of "public goods" in varying degrees. These can flow from investment in physical infrastructure and natural capital ("hard" adaptation efforts, such as irrigation and land terracing), as well as in human capital ("soft" adaptation, including developing knowledge and skills and institutional strengthening for responding to a changing climate). Each type of investment presents different challenges in assessing potential impacts and valuing benefits. Social and knowledge investments generate benefits through the way they change the actions of individuals throughout the sector. Thus, the value of such investments must be inferred by attempting to project and evaluate the economic gains from these behavior changes. The benefits of investment in physical infrastructure flow more directly from its use; one of the key challenges, in this case, is evaluating long-term benefits from infrastructure investments.[2]

A number of environmental, technical and economic uncertainties, which need to be factored into economic analysis of adaptation activities, loom over these considerations. While this paper does not provide detailed descriptions or guidance on specific techniques for addressing these uncertainties, it presents and discusses possible approaches for addressing them and provides references for obtaining more detailed information.

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[1] Terminology in the literature on adaptation (and related literature such as disaster risk management) is not well standardized, which can be a source of confusion. Heltberg and others (2009) construct a "risk-vulnerability" chain for social risk management generally and show how it applies to climate change adaptation. In their framework, risk is the chance of loss (which can be measured using various metrics) for households or other social units stemming from an external force like climate change. Exposure to risk depends on the size and distribution of assets, the mix of strategies and activities for livelihoods, and external shaping influences (government policies, cultural influences). Expected losses, after taking into account ex-ante and ex-post risk management strategies, depend on risk, exposure, and the nature and effects of risk management strategies taken. In this context, climate change adaptation is a risk management strategy. As noted in Section 2, adaptation can be further divided into autonomous activities undertaken by households and other social units, and planned activities undertaken at a more collective level by governments.

[2] Heltberg and others (2009) emphasize the importance of a broad asset-based approach to adaptation that more systematically formalizes the ideas presented here. They argue that household well-being depends on both the assets available to the household, broadly defined, and the livelihood strategies that reflect use of these assets. Assets in turn can be broken down into standard measures of: physically accumulated wealth; knowledge and human capital; natural assets, including ongoing benefits derived from being in a particular location; and those related to social and political institutions.

2. CHALLENGES IN EVALUATING ADAPTATION INITIATIVES IN AGRICULTURE

2.1 CLIMATE CHANGE AND ADAPTATION IN AGRICULTURE

Since the challenges of climate change for agriculture have already been extensively documented, we provide only a quick summary here (see Padgham 2009 for more details). During the last several decades, we have seen higher average temperatures across the globe, an increased occurrence of heavy rainfall events and floods, and longer and more intense droughts in many regions of the world. These occurrences have often led to reduced crop yield levels and disruptions in agricultural production, especially in the most vulnerable and least prepared countries.

Over the next few decades, climate change impacts on agriculture are likely to increase due to greater climate variability, and increased frequency and intensity of extreme events, not only from changes in average climatic conditions. In the longer term, these systemic climatic changes are likely to reshape the geography of agricultural land worldwide. The most vulnerable agricultural systems occur in arid, semi-arid and dry sub-humid regions in the developing world, where high rainfall variability and recurrent droughts and floods regularly disrupt food production, and where poverty is pervasive. Only a few regions, including northern China, Eastern Europe, northern North America, and the Southern Cone of South America, might benefit from a poleward shift in agriculture under a limited degree of future warming. Other areas may benefit, at least for a time, from the carbon fertilization[3] effect, which could compensate negative impacts on yields due to temperature increases and changes in rainfall (see Cline 2007).

The risks that climate change poses for agriculture are both direct and indirect. Potential direct impacts include the effects of temperature rise and changes in precipitation frequency and intensity on crop growth. Temperature rise alone is

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[3] Carbon fertilization is defined as an increase in plant growth attributable to a higher-than-normal carbon dioxide concentration in the environment. The benefits for agricultural productivity from carbon fertilization are difficult to gauge because they depend on many variables (i.e., crop type, latitude, soil conditions and management practices, etc.). As a consequence, impact estimates accounting for this effect are lower than those that do not account for it, but are affected by high uncertainty.

likely to result in reduced food production within the next couple of decades in areas already facing food insecurity, especially in low-latitude regions. Temperature rise, combined with changes in timing, magnitude and distribution of precipitation, is likely to increase moisture and heat stress on crops and livestock, with the subtropical regions being among those most impacted. Potential indirect impacts include: heightened risks of soil erosion, runoff and landslides; decreased river flows in the dry season caused by reduced glacier runoff; and increased crop losses from insects, diseases and weeds. These impacts are likely to be very acute without any adaptation (the so called "dumb farmer" syndrome). In reality, some degree of autonomous adaptation (see 2.1.2) will occur, especially where adaptation capacity is higher, which will reduce productivity losses. Still, the residual damage from climate change, net of autonomous adaptation, may be substantial in a number of areas, especially those with the poorest populations (World Bank 2008a).

2.1.1 ADAPTATION AND NO-REGRET INVESTMENT

Adaptation in agriculture entails sustaining rural development in the context of risks from a changing climate.[4] However, many, if not most, of the needed investments and other activities will also bring benefits, irrespective of how much the climate changes, for one of the following reasons. In other words, actions identified as good risk management strategies for adaptation to climate change also can be valuable parts of broader strategies that benefit livelihoods and mitigate other risks. First, adaptation investments could increase resilience to current climate variability, while also preparing for a future increase in variability due to climate change. This possibility reflects the presence of an "adaptation deficit" that diminishes the efficiency of the agriculture even in the context of current climate conditions (see *Box 1*). Second, many responses will have benefits beyond managing climate risks (e.g., improving water-use efficiency in areas that are already water-scarce due to non-climatic pressures, such as increased water demand from different sectors). In both cases, these adaptations are referred to as "no-regret" investments. Examples of no-regret adaptation responses in agriculture include (Padgham 2009):

- Improving access to new crop varieties and other production factors, which can help farmers improve overall production and better manage risks from droughts and floods.
- Enhancing resilience of the resource base to extreme climate events through conservation agricultural practices that protect soils against runoff and erosion, promote biodiversity and conserve water.
- Modernizing irrigation systems, which can increase water-use efficiency, bring greater flexibility to water delivery for agriculture, and help farmers diversify to better manage climate risks.
- Improving coordination around the containment and management of invasive alien species, which is needed for managing both current risks from invasive species and for building the capacity to cope with an expected increase in this risk with climate change.
- Creating opportunities for rural livelihood diversification, which can lead to increased economic security and less reliance on climate-sensitive agricultural activities.

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[4] From a narrow economic perspective, this may not be true in some areas, especially marginal areas. When investments to sustain livelihoods in marginal areas are not economically justifiable, one may argue that abandonment of rural marginal areas and migration is a better adaptation strategy. But in this case, other issues (i.e., overpopulation in urban areas leading to public health problems and/or social unrest) may arise.

BOX 1 WHAT IS MEANT BY "ADAPTATION DEFICIT" AND "MALADAPTATION"?

"Adaptation deficit" refers to circumstances in which even under existing climatic conditions, the agriculture sector is less productive, less efficient and less resilient to unanticipated shocks than it could be. Adaptation deficits have arisen, for example, where: agricultural development has been neglected for a number of years (i.e., in drylands and other marginal areas that have not benefitted from investments and subsidies, generally targeting high potential areas); lack of access to markets (including due to protectionist policies in other countries) limits economic returns to increased crop diversity; and lack of access to knowledge or credit constrains the use of more efficient practices and resilient crops. In the presence of an adaptation deficit, policies and investments that improve efficiency and resilience today will also contribute toward making agriculture more adaptable to future climate change. In this respect, they are "no-regrets" measures for both current and future agricultural activity. For this reason, it is becoming more common to refer to the problem as a "development deficit" rather than just as an "adaptation deficit."

"Maladaptation" refers to interventions that, in addressing specific development objectives, end up being counterproductive with respect to adapting to climate change or supporting the adaptive capacity of local communities. An example is the presence of wasteful water subsidies that damage the environment (e.g., by reducing environmental flows) and create incentives for cultivation of water-intensive crops, irrespective of water-use efficiency considerations. A more subtle case of maladaptation exists in projects that aim to implement some type of planned adaptation, but may end up lowering local adaptive capacity and/or creating disincentives to autonomous adaptation. An example is an agricultural project that supports monoculture of a high-value crop, with the objectives of maximizing the irrigation system efficiency, water productivity and yields ("more crop per drop"), and, ultimately, of boosting income generation. Although such a project might be designed taking into account the effects of climate change on the local climate and hydrological conditions, in the absence of insurance against yield losses, it would lower the adaptive capacity of farmers by making their income generation base more volatile. In the case of a bad harvest, farmers' income would be greatly affected, i.e., the ultimate impact of the project would be one of increased vulnerability to climate risks.

Source: Authors.

On the other side of the spectrum, there may be responses whose benefits stem mainly from addressing climate change risks, such as infrastructure projects (e.g., dams, dikes) designed specifically to proactively respond to projected changes in factors such as runoff and sea level rise as a consequence of climate change. The latter investments could have "higher regret," meaning that explicit consideration of the uncertainty of climate change in the evaluation is even more important (see 3.2). Of course, timing matters: adaptation measures can be separated according to a time dimension, e.g., with reference to short-term, medium-term and long-term temporal horizons (*Kurukulasuriya* and Rosenthal 2003). Moreover, the decision to act now or later is an important aspect of project evaluation, particularly for higher-regret investments (see 2.2.3).

While adaptation strategies, policies and activities can take place as stand-alone measures, they may be more effective when integrated into broader efforts designed to improve the livelihoods of communities dependent on agriculture (e.g., expansion of extension-type services, introduction of more cost-effective cultivation methods). However, a risk that must be addressed is that projects pursuing broader development objectives could be counterproductive with respect to adaptation to climate change, including supporting the adaptive capacity of local communities. ***Box 1*** further discusses this risk.

2.1.2 CLASSIFICATION OF ADAPTATION

Table 1 below provides a summary of the types of adaptation activity relevant to our purposes. *Autonomous* or *private* adaptation involves actions by farmers, communities and others in response to the threats of climate change perceived by them, based on a set of available technology and management options. Autonomous adaptation is implemented by individuals only when considered cost effective by those implementing it, i.e., when adaptation is in their self-interest (Mendelsohn 2006). Potential examples include selecting different technologies, changing crops, inputs and management practices suited to the new environment, shifting crop calendars, and changing irrigation schedules.

Planned or *public sector* adaptation involves action by a local, regional and/or national government to provide needed public goods and incentives to the private sector to fit the new conditions. For example, if climate change is expected to affect water availability (i.e., runoff) and demand, water harvesting infrastructure can be built and/or water can be reallocated among users. Referring again to *Table 1,* the first intervention (water harvesting infrastructure) is an example of a *"hard" adaptation* investment, while the second (water reallocation) is an example of a *"soft" adaptation* investment via modified institutions and incentives. Soft adaptation actions alter the circumstances in which private sector decisions are made (in particular, autonomous adaptation decisions) and their value must be assessed in that light (Agrawala and Fankhauser 2008).

Other examples of planned adaptation (taken from Rosenzweig and Tubiello, 2007) include:

- modernization or development of new irrigation infrastructure
- transport and storage infrastructure
- land-use arrangements and property rights
- economic incentives for sustainable land uses
- water pricing
- watershed management institutions
- training for the private and public sector/ capacity building

TABLE 1 SUMMARY OF ADAPTATION CATEGORIES BY TYPE

Adaptation classification		Examples
Autonomous Private sector	Sectoral	Change crops, crop calendars, irrigation schedules
	Economy-wide	Market adjustments in crop prices reflect new production levels
Planned Public sector	Hard	"Climate proof" infrastructure, including irrigation systems and rural roads
	Soft	Seasonal climate forecasts, capacity building, research and extension on drought resistant crops, local institutions, economic incentives for efficient water use

Source: Compiled from material in Agrawala and Fankhauser 2008.

- economic incentives for efficient water-use technologies
- agricultural research on drought-resistant crops
- financial services (microcredit, insurance)

All but the first two are other examples of soft adaptation. Although each of these activities could also be part of "business-as-usual" agricultural development initiatives, the common denominator for our purposes is that they represent responses to anticipated changes in climate (including increased variability).

Development projects focus on public investments in adaptation. Therefore, planned adaptation is the focus of this paper. Nevertheless, autonomous adaptation must be taken into account when defining the "baseline" or "without-project" scenario. Moreover, in project evaluation, it is important to consider how planned adaptation may influence the private sector's capacity to undertake autonomous adaptation.

2.1.3 ADAPTING TO CHANGES IN CLIMATE VARIABILITY AND TO MEDIUM-LONG TERM CLIMATE CHANGE

Partly as a consequence of uncertainty over future climate change impacts (see 2.2.1), individuals, communities and institutions often put a priority on strengthening shorter-term responses to current climate variability (Callaway 2004). Given the impacts of current climate variability on development outcomes and projections of increasing variability and extremes in the coming decades, many developing countries are likely to aim first at making communities and natural systems more resilient to both current and future climate variability (including, for example, increased frequency of extreme events). Nevertheless, future climate change trends must be taken into account when development outcomes depend on how the climate will change in the next few decades. For example, the design of a new irrigation system warrants consideration of the expected water availability during the project's lifetime, which is generally 20-30 years. Some longer-term climate-change related risks already seem very likely in the next few decades, with high expected impacts, (e.g., melting of glaciers threatening to compromise water availability in entire watersheds in the Andean region). In these cases, adaptation needs to deal with medium-to-long term changes in overall climatic conditions, as well as changes in variability.

2.2 ASSESSING THE COSTS AND BENEFITS OF ADAPTATION

Project economic analysis calls for defining the "baseline" or "without-project" scenario. For a stand-alone adaptation project, both benefits and costs can be assessed relative to a no-project alternative. For a project with adaptation components undertaken within a broader set of activities, the comparison would be made relative to a business-as-usual project without adaptation components. In either case, but especially in the latter, there is an inherent subjectivity and need for expert judgment in defining the hypothetical alternative as a basis for comparison. Indeed, unless specifically called for to isolate and value adaptation components (see 3.2.1), it may be more useful simply to value alternative project designs, including different adaptation components, without differentiating between adaptation and broader objectives.

Another important aspect in economic analysis is the consideration of "co-benefits." The economic assessment of any agricultural development project can and should consider adaptation co-benefits of investments that help facilitate autonomous adaptation or increase adaptive capacity as a by-product. One example is an agricultural project which aims to increase agricultural productivity through improved water efficiency in an area that is already water-scarce.[5] On the other hand, when carrying out an economic assessment of any stand-alone adaptation project, it is always important to consider co-benefits, in addition to the specific benefits associated with climate change adaptation (see 3.2.1).

2.2.1 DEALING WITH UNCERTAINTY IN THE ECONOMIC ANALYSIS OF ADAPTATION

The estimation of costs, benefits and effectiveness of any investment project generally raises a number of methodological issues. Even without considering climate variability and change, for example, the economic analysis of an agricultural project will depend on assumptions made on future crop, input and energy prices, development of export markets, and patterns of rural-urban migration. By the same token, for many investments—particularly those involving environmental or social capital—uncertainty exists regarding the economic value of the non-market benefits. Climate variability and change, and responses to them, add other dimensions of uncertainty to project evaluation, even over a medium-length time horizon (20-30 years). Specific sources of uncertainty include the following:

- Uncertainty over the underlying physical or ecological processes. Longer-term climate change impacts remain uncertain, particularly for use in most project-level planning and management decisions, for several reasons. First, future greenhouse gas (GHG) emissions are unknown, as they critically depend on global economic growth and mitigation efforts. In addition, the relationships between GHG concentrations, temperatures (regional or global), and climate patterns are complex and uncertain (Pindyck 2007). Different global-scale models assuming the same emission scenarios often disagree about scale and sometimes even about the direction of climate change impacts, particularly at the regional and subregional levels. Projections are provided via a range of estimates, frequently with limited information about confidence intervals. So, even if we could determine GHG concentrations in the next 20-50 years, estimating expected impacts on precipitation, biodiversity, agricultural yields, etc. would be challenging. Furthermore, information remains sparse regarding how climate changes and socioeconomic changes might interact, even though individual and institutional responses are critical determinants of climate change damages.
- Uncertainty over the damages avoided or mitigated through adaptation. Additional uncertainty arises from the relative lack of experience in evaluating the benefits of adaptation measures. We have already alluded to two components of this challenge. One is the challenge of tracing through the impacts of interventions, particularly those related to soft investments in knowledge and

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[5] Actions to increase a society's fundamental or "raw" adaptive capacity (Sen 1999)—for example, investments in nutrition, education and health services—may also, in principle, be included within the purview of climate change adaptation because they contribute to making communities less vulnerable to climate risks. For example, education allows new generations to engage in income-generating opportunities other than agriculture. This type of investment could be considered an extreme case of "no-regret" adaptation. However, our focus here is on adaptation measures more directly related to resilience to climate variability and change.

institutions whose benefits are realized by a range of changes in private behavior (see 3.2.1). The other is the continuing challenge of how to evaluate physical or ecological impacts in monetary terms. This may be relatively manageable in examining the value of changes in tangible resource availability, such as water. It is more difficult when ecosystem changes (i.e., land degradation) might affect agricultural productivity in several ways that remain poorly understood. In these cases, a non-economic evaluation approach might be recommended (see 3.2.2).

Nevertheless, the real challenge for the economic evaluation of adaptation goes beyond the lack of climate change data at the "square centimeter level" or uncertainty surrounding which climate change scenario is likely. It has more to do with the absence of a systematic approach to explicitly make informed decisions under uncertainty (see 3.2.3 for a discussion of possible solutions).

2.2.2 DECIDING BETWEEN INVESTING NOW OR LATER

Decision makers have choices about when to invest as well as how much and in what form. When making a decision, a key issue regarding the timing of adaptation interventions is the evaluation of benefits and costs over time. Standard economic net present value (NPV) analysis discounts future costs and benefits to a common base year using a specified rate of discount. Numerous debates exist with respect to the choice of this discount rate in project assessment. Conceptually, one seeks a discount rate that reflects the social opportunity cost of capital (Bosello and others 2007), but in practice there is much controversy over what that rate should be. As noted, the controversy is sharpened in cases of long-lived investment projects.

When to invest also depends on the time profile of benefits. Soft adaptation projects may yield the greater share of their benefits over a relatively short term (a few years). Investments in local infrastructure that have a somewhat longer economic life (e.g., 10-30 years) may also deliver the greatest benefits in the near term. Where such investments have high co-benefits in reducing a current adaptation deficit, the argument for more rapid investment is further strengthened.

Deciding how much to adapt now, versus waiting to do more in the future, also depends on difficult to evaluate tradeoffs related to uncertainty. In particular, waiting can deliver a benefit from gaining additional information on the impacts of climate change and the options for ameliorating those impacts. However, the magnitude of this benefit is uncertain and needs to be weighed against the cost of delaying adaptation. For example, in circumstances where the impacts of climate change or increased climate variability pose serious threats to the livelihoods of whole communities, an adaptation measure implemented now might give the affected population the possibility of remaining in place versus the need to relocate when climate change hits hard in the future. On the other hand, large commitments of fixed capital to adaptation-oriented infrastructure investments may foreclose options to pursue more gradual or different types of adaptation in the future (see Fankhauser 2006 for more discussion of these issues). How one might try to gauge the value of such options is one of our topics in the next section (see 3.2.2), where we also address the related issue of long-term discounting under uncertainty (see 3.2.1).


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3. APPROACHES AND METHODOLOGIES FOR EVALUATING ADAPTATION

The problem of economically evaluating adaptation to climate change at the project level can be disaggregated into two distinct subproblems, namely:

1. Evaluating the potential impacts that climate change could have on agricultural productivity in the project area, assuming either no adaptation at all or only autonomous adaptation.
2. Evaluating costs and benefits of possible planned adaptations, including the implications of uncertainty with respect to the choice of specific adaptation options.

These assessment stages are common to the evaluation of adaptation in any sector. The specific approaches and methodologies that can be used to deal with each subproblem, on the other hand, can be different depending on the sector and the specific project's characteristics. In the remainder of this chapter, we will describe some possible methodologies for addressing each subproblem from the perspective of an agricultural project, and illustrate their application by referring to specific project assessments. We will also underline the need for more applied research to make current assessment methods more suited to application at the project assessment level.

3.1 ASSESSING THE IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL PROJECTS

In the last few years, the research community has developed a few alternative methodologies (either new approaches or adjustments of existing ones) that can be used to carry out an economic analysis of climate change impacts on agriculture. Two approaches in particular — one from the agronomic field and one from the economic field — have become the most widely used in applications to country studies and projects dealing with climate change impacts and adaptation in agriculture. These are the agronomic (or crop) models and the Ricardian (or hedonic) models.[6] A third

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[6] Pradeep and Mendelsohn (2008) further divide the approaches into four categories: agronomic, panel data, agroeconomic and Ricardian.

approach, developed in the engineering field for the estimation of disaster risk and based on probability functions, may be promising for application to extreme events. We briefly describe each of these in the following sub-sections, providing some examples in text boxes.

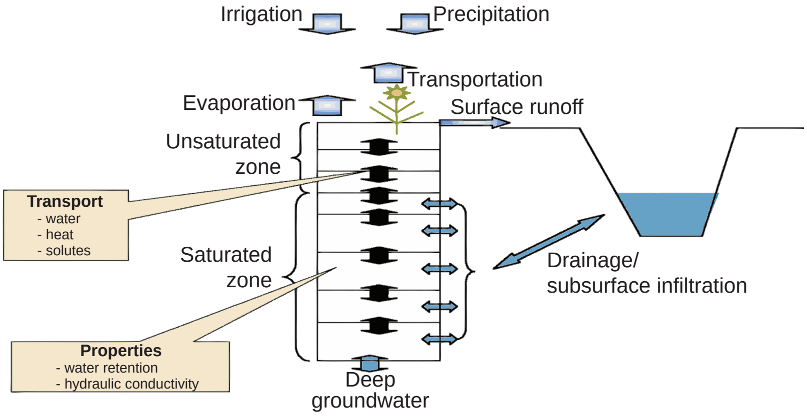
3.1.1 AGRONOMIC OR CROP MODELS

These models are biophysical representations of crop production simulating the relevant soil-plant-atmospheric components that determine plant growth and yield (see *Figure 1*). They can be used to assess the impacts of climate change on agricultural productivity, as well as to investigate the potential effects of different adaptation options. Examples are planting and harvesting methods, fertilization, irrigation, change of crops and cropping mix, and timing and/or amount of irrigation. Crop models can be part of more complex "integrated models," where different components (i.e., climate, water balance, crop production and economic modules) interact with each other.

Agronomic models assess vulnerability to climate change, in terms of expected yield losses, of local or regional agricultural production systems. Seasonal dynamics and inter-annual variability can be accounted for by some models. Some recent applications aim to model the impacts of flood extremes (see *Box 2*), as well as long-term crop production under conditions of increased climate variability (i.e., more frequent dry spells or more intense rainfall). A summary table describing the main characteristics of some commonly used agronomic models in climate change applications is provided in Padgham (2009).

Agro-economic models include an economic module and can be used to assess the economic impact of climate change on agriculture, and reduced economic losses for farmers from implementation of particular adaptation practices. Costs of autonomous adaptation that fall on individual farmers can be accounted for (i.e., cost of fertilizers, energy costs for irrigation, etc.), while costs of planned adaptation (i.e., the investment cost of a water reservoir for irrigation serving a

FIGURE 1. STYLIZED SCHEMATIC ILLUSTRATION OF A SOIL-WATER-CROP MODULE (BASED ON SWAP-WOFOST MODELS)



Source: Nkomo and Gomez 2006.

BOX 2 IMPLICATIONS OF CLIMATE CHANGE ON FOOD SECURITY IN BANGLADESH

This World Bank study in Bangladesh has the objective of assessing future food security issues associated with climate change at the country level (primarily focused on 2030 and 2050 time frames), taking into account both changes in mean climate variables and climate extremes. Given the comprehensive purpose of the study, many different models have been applied, whose results have been integrated to provide a comprehensive picture of the degree to which climate change is likely to pose a risk to food security in the coming decades.

Among these, a crop model (DSSAT) is being used to derive estimates of crop production throughout the country. The model is being calibrated with realistic local-level information on soils, crop management practices, weather data, cultivars used, planting schedules, etc. In addition, an analysis of historical climate risks is being undertaken to examine empirical relationships to crop production. Upstream water demand changes as a result of climate change, as well as flood damage yield functions, have been factored into the crop models.

More specifically, basin and national-level hydrologic models (namely, the DHI Mike 11 model and an in-house Ganges-Brahmaputra-Meghna Basin regional model) are being employed to produce information on future characteristics of floods in the country. These hydrologic models are being calibrated to Global Circulation Models parameterized to track 20th century historical scenarios. (These large-scale computer simulation models are designed to reproduce key features of the very complex processes making up the global climate system.) The DSSAT crop model has built in flood damage yield functions that utilize output flood characteristics from the hydrologic models.

Source: World Bank, 2009a.

vast area) cannot be included in such farm-level assessments.

An important advantage of these models is their flexibility, particularly due to the possibility of adding or removing specific modules and representing local conditions in some detail.[7] This allows for tailoring to specific local conditions. For example, they can easily be linked to global or downscaled circulation models, and outputs from these models can be used as inputs to a "weather module" to simulate the effects of climate change on future daily weather, and then on agricultural production. At this point, yield outputs can become inputs to economic models that calculate the economic value of production or farmers' income (see *Box 3* on an application in India).

By far the most important issue related to the use of these models for project-level assessment is the fact that they are calibrated using historical relationships between independent variables (i.e., soil profile, climate data, management practices) and production outputs. However, these relationships are likely to overstate the longer-term potential future impacts of climate change, since they do not adequately allow for autonomous adaptation

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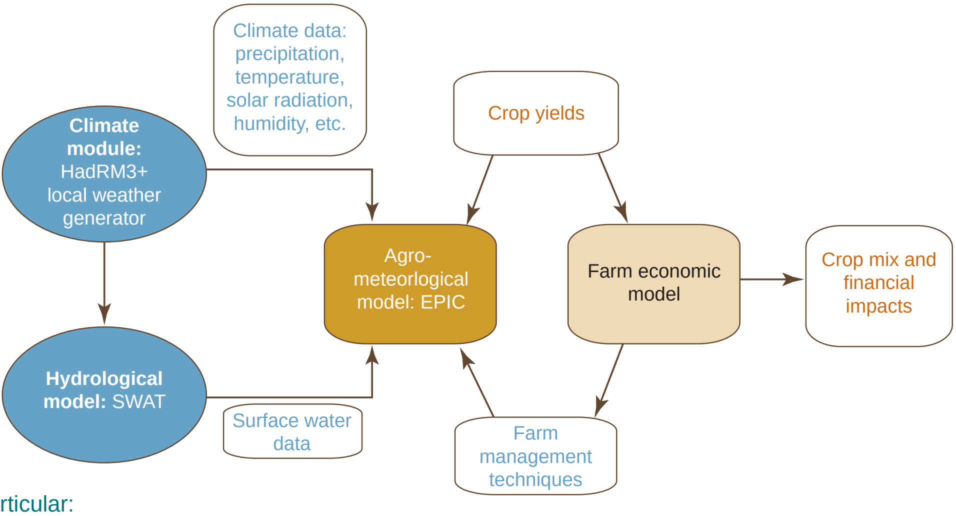
[7] For example, the DSSAT model is comprised of the following modules: Land, Management, Soil, Weather, Soil-Plant-Atmosphere and Plant Growth modules.

BOX 3 CLIMATE CHANGE IMPACTS IN DROUGHT AND FLOOD AFFECTED AREAS IN INDIA

This World Bank study in India aims to enhance the understanding of climate and climate-related issues in the Indian agricultural sector, focusing on areas particularly vulnerable to droughts and floods. The Integrated Modeling System (IMS), developed for the purposes of this study, consists of three subcomponents—a regional climate model (HadRM3), a hydrological model (SWAT) and an agro-meteorological simulation model (EPIC)—and their functional links. These subcomponents are, in turn, linked to an economic model.



In particular:

- The starting point for the IMS is the generation of regional climate data based on IPCC emissions scenarios (IPCC 2009); climate projections have a spatial resolution of 50 km x 50 km and are generated for 2070 to 2100.
- A stochastic weather generator projects these climate impacts to the local level.
- The resulting climate data is then used in the hydrological model, or SWAT, to generate surface water data, required as inputs to run the agro-meteorological model.
- The agro-meteorological model EPIC integrates water and climate data into an agricultural output estimation framework.
- Finally, a custom-built farm-level economic model interacts with EPIC to assess the financial impacts of climate change on farmers and to determine effective adaptation strategies. The basic assumption is that farmers respond to the actual weather by adopting management techniques that maximize their payoffs (for instance, in dry years it may be necessary to irrigate some crops more intensively and reduce water allocations for other crops. If this occurs, it will also be necessary to adjust fertilization rates). The EPIC module predicts yields under different management regimes, while the corresponding economic module computes the associated payoffs.

Source: World Bank 2008b.

by the affected farmers whose activities are being modeled. Moreover, the "without-project" damages are overestimated to the extent that they cannot incorporate the effects of future technological change. By the same token, crop models can overstate the positive impact of a planned adaptation initiative by not considering how autonomous adaptation already partly offsets the adverse climatic impacts. How serious this bias is will depend on available opportunities to those covered in the analysis for autonomous adaptation. A similar problem arises in trying to gauge the contribution of soft adaptation efforts. These efforts are, in fact, designed to change the parameters related to farm-level inputs and outputs. For example, training on more effective fertilizer use will increase the yield per application of fertilizer.

Operationally, data requirements (i.e., soil profile data, weather data, local management information, etc.) can be demanding for these models, especially for project-level applications. If data availability is a constraint, an option is to apply less data-intensive agro-meteorology techniques, where the impact on yields is based only on changes in crop evapotranspiration (see *Box 4* for an application in Morocco). In terms of time and resources, the costs to benchmark and run a model may be considerable.

3.1.2 RICARDIAN OR HEDONIC METHOD

The Ricardian method was pioneered by Mendelsohn and others (1994) to estimate the longer-term effects of differences in climatic conditions on agricultural land values, and is based on the idea that long-term land productivity is reflected in the land's asset value. Given that the farmland is being used in the best possible way, and given environmental conditions, factor prices and other constraints, observed market rent on the land (or farmland value) will be equal to the annual net revenues from production of the cultivated crops or livestock.

The impacts of different influences on land value, including climatic differences, are econometrically estimated using cross-sectional data (i.e., data on agricultural land at different locations at a given time). The effect of various other influences, such as socioeconomic conditions, soil and geographic characteristics, can be controlled to provide estimates of the effect of climate variables on land values. After estimating how climate conditions (i.e., changes in temperature or precipitation) affect land values, it is possible to use climate scenarios to infer the impact of climate change on the value of farmland and, hence, on its productivity.

Ricardian approaches have been used to provide analyses of the longer-term economic vulnerability of agriculture to climate change in:

- large countries — India and Brazil (Sanghi and Mendelsohn 2008), China (Wang and others 2007) and the United States (Schlenker and others 2006);
- small and medium countries — Cameroon (Molua and Lambi 2007) and Egypt (Eid and others 2007);
- small islands — Sri Lanka (Kurukulasuirya and Ajwad 2006);
- continents as a whole — Africa (Kurukulasuriya and others 2006) and Latin America (Seo and Mendelsohn 2008a).

These approaches have also been applied to estimate impacts on the livestock sector (Seo and Mendelsohn 2008b).

An important strength of this methodology is that the findings on longer-term climate change impacts are net of whatever autonomous adaptation responses to climate change individual

BOX 4 IMPACTS OF CLIMATE CHANGE IN THE AGRICULTURE SECTOR IN MOROCCO

This World Bank study in Morocco purports to evaluate climate change impacts and identify adaptation options by means of a combined climatological, agronomical, hydrologic and economic approach. The structure of the study includes: the construction of scenarios of mean daily temperature and precipitation based on climate change projections (derived from a Statistical DownScaling Model); a yields impact module based on agro-meteorology techniques (unlike crop models, these techniques estimate the impact on yields based only on changes in crop evapotranspiration, without considering soil characteristics); a hydrological study to evaluate climate change impacts on surface and ground water; and an economic General Equilibrium Model disaggregated by agro-climatic conditions, access to irrigation and farm type diversity.

Selected outputs of the study include:

- Yield impacts of climate change on rainfed and irrigated major crops at 9 regular time intervals for 4 climate scenarios. These scenarios are generated by combining results from two different Global Circulation Models, and two projections of future economic activity and emissions from the IPCC scenarios (IPCC 2009).
- The additional demand of water to offset the yield effects of climate change.
- Availability of water for irrigation from dams, taking into account the growth in demand for municipal and industrial use, the reduced inflows that will result from increased temperature and reduced rainfall, and the rules that govern allocation of water across different uses (estimates disaggregated by major dam).
- Change in groundwater recharge due to change in rainfall and temperature, and increase in costs of groundwater extraction due to a combination of reduced aquifer recharge and over-extraction (estimates disaggregated by major aquifers).
- Adjustment of the economy as a whole (and of the agricultural sector in particular) to changing climatic conditions. For example, changes in agricultural value added, employment and agricultural trade will be estimated under different scenarios (incorporating assumptions regarding demographics, labor force, savings and investment behavior, and productivity).
- Evolution of both the “median” equilibrium solution for the variables of key policy interests and of extremes (e.g., with probability of 5% or 10%) in order to inform policy on low-risk, high-impact events.
- Optimal mix of adaptation responses based on net marginal benefits.

Source: World Bank 2009b.

farmers are able to make over the longer term. In applying this approach, it is assumed that over the longer term, a new climate regime will induce geographic redistribution of agricultural activity and other behavioral changes that are reflected in how farmers have already adapted to different climate conditions in diverse geographical areas.

Earlier applications of Ricardian methods tended to produce models that were, to some extent, “black boxes” with respect to the identification of actual adaptations by farmers. This also poses an obvious constraint on the analysis of specific planned adaptation measures. However, the most recent models are increasingly able to provide

BOX 5 AN EXAMPLE OF NEW GENERATION RICARDIAN MODELS

Kurukulasuriya and Mendelsohn (2008) examine the impact of climate change on primary crops grown in Africa. They propose an innovative approach that aims to bridge the gap between agro-economic and traditional Ricardian models, and label it a "structural Ricardian" model.

A simple model of the farm is developed where a farmer first chooses a desired crop or crop combination and then earns a conditional income based on the crop chosen. By modeling crop choice across different climates and measuring the role that climate plays in these choices, this approach reveals one of the explicit adaptations that farmers make, thus overcoming a primary limitation of the traditional Ricardian models. The resulting model can be used to predict the effect of climate change scenarios on expected net revenue, both with or without changing crops.

The model is estimated using a sample of over 5000 farmers across 11 countries in Africa, with the analysis concluding that farmers shift the crops they plant to match the climate they face. According to the authors, by accounting for crop switching, the damages from climate change are not overestimated and the benefits not underestimated.

Source: Kurukulasuriya and Mendelsohn 2008.

information for answering these kinds of policy-relevant questions. In particular, the latest generation of "structural Ricardian" models (Kurukulasuriya and Mendelsohn 2008, and Seo and Mendelsohn 2008a and 2008b) can model crop/livestock, irrigation and farm-type choices using a multinomial probability setting, and are more capable of distinguishing among different agro-ecological zones (see *Box 5*).

The Ricardian method has not traditionally been applied for assessing planned adaptation projects, but it could be, in principle. Consider a hard investment like water storage or irrigation. To the extent that similar kinds of infrastructure investments were included as explanatory variables in the equation for the land value, it is possible to look at how an increased availability of infrastructure services combined with projections of a changing climate would affect land values, and thereby deduce a value for the benefit of the investment. If infrastructure were not included as an explanatory variable, then it would be necessary, for example, to somehow convert the increased availability of water to an equivalent change in the climate. However, this would be more subjective and prone to error. More complex issues arise in evaluating soft adaptation investments. For example, if a measure of know-how was included in the estimate, the application would be reasonably straightforward. If not, then it would be difficult to separate the influences of the capacity-building investment from the unmeasured autonomous adaptations.

Therefore, in some cases, the Ricardian approach can be applied to assess the "with-project" scenario. The counterfactual "without-project" scenario would call for a different approach, such as the application of a crop model. Although a quantitative comparison of the two models is not feasible, a qualitative comparison can indicate roughly the value of adaptation measures in response to climate change, if the Ricardian model is correctly specified in order to reflect, to the extent possible, the adaptation measures promoted by the project. Crop models, in particular, can provide a baseline case corresponding to an assumption of current farming practices and environmental conditions except for the changes in temperature and precipitation specified in the crop simulation models. The Ricardian model, on the other hand, "allows" farmers to move from one set of crops and/or technology to another as the climate changes, providing an estimate of the benefits derived from adaptation (although limited to the observed ones in the particular region). An example of the joint application of a crop and a Ricardian model for project evaluation is provided in *Box 6*.

Operationally, the Ricardian approach relies on data collected through surveys among farmers, where questions about farm types, crop cultivation and other activities during a farming period are asked. These surveys need to be carried out in districts and villages chosen to get a wide representation of farms across climate conditions in the area of interest. Moreover, local data on climate, soil and hydrology are needed, and, above all, reliable independent measures of land values are required. As a consequence, costs of obtaining the data for carrying out this analysis may be high, especially for a smaller versus national-scale project. For smaller geographical levels (i.e., project level), this approach can be successfully applied if a national-scale study is already available (see *Box 6*).

For a full list of strengths and weaknesses of the Ricardian approach, see Kurukulasuriya (2006). For our purposes, a few advantages and disadvantages of this method with respect to the crop model approach are discussed here.

An advantage of the Ricardian approach over crop models for assessing climate change impacts is that the economic impacts can be modeled even in the absence of a full understanding and modeling of the biophysical impacts of climate change and the impacts of specific adaptation measures. In principle, the effects of changes in climate variability and frequency/severity of extreme events could also be assessed with a Ricardian approach. This is possible as long as differences in these climatic attributes are included in the cross-sectional data and their effects can then be reflected in land values independent from long-term climatic differences. However, in practice, this may prove to be a difficult task.

An important caveat of the Ricardian analysis is that variations in the amount of water available at the farm level are not considered; the approach implicitly assumes that sufficient water is available at a particular location to accommodate the specific adaptation measures undertaken by farmers. Crop models are better equipped to deal with water availability issues if linked to an upstream hydrological module that calculates water available for plant growth. Another issue with Ricardian models is that the carbon fertilization effect cannot be addressed, while the crop model analysis can account for it.

Institutional and technical constraints to autonomous adaptation also may be difficult to measure in a number of cases. These constraints could be rooted in local culture and habits, or the lack of know-how in some regions. In a Ricardian analysis, this is not a problem if these factors stay constant over time. If they change, however, those omitted influences could lead to biased estimates of the potential effectiveness of autonomous adaptation. Similarly, future technology advances are not factored in. If these changes imply less climate change sensitivity, then omitting them leads to an overestimation of impacts from climate change despite the incorporation of autonomous adaptation. Finally, by their very nature, Ricardian models do not provide insight regarding how autonomous adaptation practices would be phased in over time. Crop model

BOX 6 ADAPTATION FOR IRRIGATED AGRICULTURE IN CHINA

The ongoing “Mainstreaming Climate Change Adaptation in Irrigated Agriculture” project in China (World Bank 2008b) used a two-model methodology to assess the benefits of the proposed adaptation measures in the project area (3H Basin). In particular:

- A set of biophysical process-based crop models was used to simulate the impact of expected climate change on yields of major crops in pilot locations (the “without-project” or without adaptation case).
- A farm-level, statistically-based economic (Ricardian) model estimated the impact of farmer adaptation to climate change on farm income (the “with-project” or with adaptation case).

The Ricardian climate estimates were taken from a recent statistical analysis of agricultural sensitivity in China (Wang J., Mendelsohn R., Dinar A., Huang J., Rozelle S., and Zhang L. 2007). Climate change scenarios (assessed in both the crop and the Ricardian models) included a combination of: (a) increased temperature of 0, 2 and 5 degrees; and (b) increased and decreased precipitation of 0 percent, +15 and -15 percent, and +30 and -30 percent mm/year. Changes in variations by season were not simulated.

To estimate the economic impact of adaptation at the local county level, the present climate for each county was inserted into the Ricardian function in order to calculate the present net revenue per hectare. Such net revenue captures a crop mix as well as technologies and management practices that farmers already undertake in response to various perceived signals, including responses to present changes in climate. Next, climate change scenarios were incorporated into the Ricardian models to calculate the change in net revenue resulting from change in climate for each country.

The comparison of results from the two models provided a “qualitative” justification for the project. Indeed, the comparison of the biophysical crop simulation models showed that reductions in maize would occur as a result of climate change without adaptation (“without-project” case), while the Ricardian model indicated that, with adaptation, net farm income can increase (“with-project” case). These results assumed that the farmers have the knowledge, guidance and support needed to implement adaptation. Given that the project aims to provide farmers with the necessary knowledge and favorable conditions to adapt, these results helped to justify the investment. In addition, the implicit models’ assumption that water is non-limiting, compared to the actual situation where water supplies are very limited in the 3H Basin, provided a justification for the project’s strong focus on improving “real water saving” as a means for climate adaptation.

Source: World Bank 2008c.

analysis, which relies on field data and expert judgment on current and future farming practices, can in principle better control for these factors, but assumptions over techniques and technologies available to farmers in the present and future need to be made explicit and justified.

An obvious final constraint that applies to both Ricardian and crop models is that farmers’ behaviors are influenced by variables that are generally not accounted for in the models, such as policies and subsidies. For example, in northern Mexico, wheat and corn are the most commonly grown crops, not because of the region's climatic characteristics, but because the government subsidizes irrigation and pays a kind of support price for these products. In principle, these variables might be accounted for, but this has not been done in the Ricardian studies published so far.

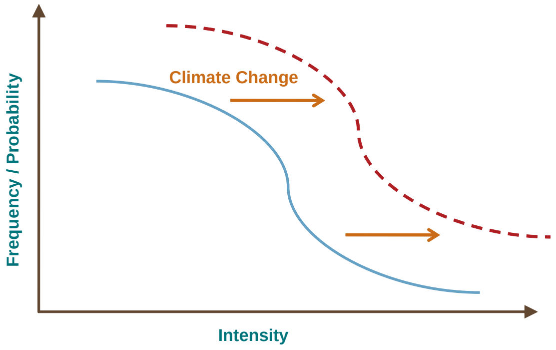
3.1.3 PROBABILISTIC METHODS FOR IMPACT ASSESSMENT OF EXTREME EVENTS

The literature on and the practice in the field of disaster risk reduction suggest another method for the estimation of expected economic losses due to climate change, as well as of economic benefits of adaptation measures (see 3.2.3). These methods were developed for application to natural disasters and, hence, are most immediately applicable to impacts of climatic extremes (i.e., floods), although it may be possible to adapt the approach to evaluate other impacts of climate change.

An *exceedance curve* showing the relationship between intensity and probability of a certain event (i.e., flood) is at the core of this technique, which allows for the probabilistic estimation of monetary losses due to natural disasters. In *Figure 2*, each point on the y-axis indicates the probability that the event has equal or greater intensity than the corresponding point on the x-axis. Thus, as the potential intensity of an event increases along the x-axis, the probability that an actual event will have impacts exceeding that level declines (ultimately falling toward zero as the target intensity grows without limit). With additional probabilistic information about the frequencies of occurrence of the climatic events of each degree of intensity over time, and about the associated economic losses, it is possible to put together an estimate of the expected cost of the occurrence of extreme events (and its variance). For high-intensity, low-frequency, events, estimating probability distributions is difficult, particularly since few historical observations are available.

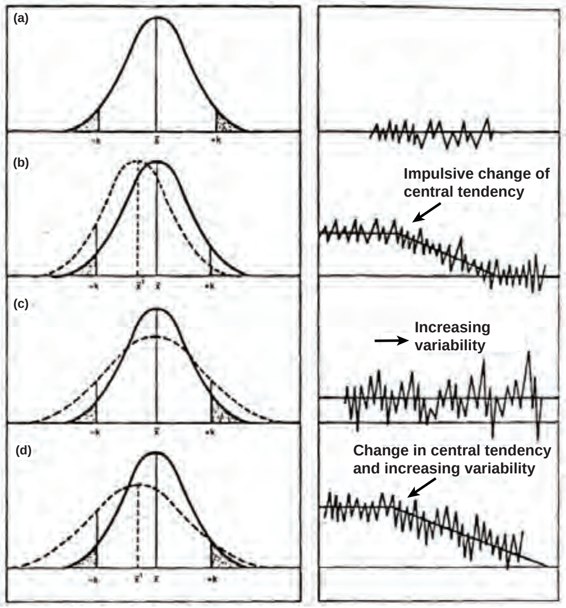
For many extreme events, climate change will have the effect of translating the curve towards the right side (due to increasing frequency and/or increasing magnitude of natural hazards). This has the effect of raising the expected impact. However, the reliance of this method on probability functions makes its use in climate change applications challenging, particularly because estimating probability functions of extreme climate events proves very difficult under climate change (see *Box 7*).

FIGURE 2 EFFECT OF CLIMATE CHANGE ON AN INTENSITY-PROBABILITY FUNCTION



BOX 7 UNCERTAINTY AND PROBABILITY FUNCTIONS

The typical view of uncertainty assumes that the distribution of possible outcomes takes the shape of a bell curve (called normal or Gaussian distribution), with equal probability that the actual outcome could be either smaller or greater than the predicted average (Gulledge 2008). A situation with no climate change is represented in Figure (a), where the left figure represents the normal distribution of the climate variable, while the right figure represents variability around the mean. Observed trends of climate variability and projections of climate change on different climate-related variables suggest that the shape of the initial probability distribution may change in the near or distant future. In particular:



Source: Scandizzo and Notaro 2008.

- In most locations, the mean values of the main climatic variables will change, i.e., the probability distribution will shift towards the left or the right side (the left side in Figure (b), left column), and climate will vary around a different mean (a lower mean in Figure (b), right column). This is what we refer to when we say, for example, that, according to a specific climate model, by 2050 the average precipitation is likely to decrease by 10% in a certain location. Unfortunately, different models may generate slightly or significantly different projections depending on the area. As a consequence, in many cases, it is not possible to estimate with sufficient confidence which direction and by how much the distribution will shift.
- Future probabilities of above- or below-average values of many climate variables will be higher than those suggested by the initial bell curve. In other words, either the right or the left tail (or both) of the probability distribution of climate variables will become "fatter" (Figure (c), left column), i.e., the climate variable will more often be farther away from the mean (right column). This is what we refer to when we say that, as a result of climate change, climate extremes will become more frequent. Depending on the climate variable, a fatter right or left tail of the distribution means higher frequency of climate extremes (i.e., if the variable is "mean annual precipitation," a fatter left tail can be interpreted as increasing droughts, while a fatter right tail means increased probability of storms/floods). Once again, in many cases, it cannot be estimated with reasonable approximation by how much the tail will get fatter.
- The two effects described above can play together (Figure (d)).

Source: Authors and W. Yu (personal communication).

Although some methods exist to help glean information about what future probabilities may look like (i.e., trend analysis, multimodel ensembles used as probabilistic climate change forecasts[8] or more sophisticated spectral approaches), possibly the best approach for impact assessment in project level analysis is a Monte Carlo-type simulation embedded in a "weather generator" linked to climate projection scenarios. A recent application in a study in India (World Bank 2008b) has proven that this method is promising and reasonably easy to apply.

3.2 EVALUATING COSTS AND BENEFITS OF PLANNED ADAPTATIONS

We assume that readers of this paper are familiar with the general application of cost-benefit analysis to project appraisal. In this section, we focus on: options for assessing benefits and costs of adaptation measures in agriculture within a cost-benefit economic framework, including issues related to the discount rate; non-economic project evaluation; and approaches for dealing with uncertainty.

3.2.1 METHODS FOR ASSESSING ECONOMIC BENEFITS AND COSTS

The challenges in evaluating unit costs and benefits of hard and soft adaptation investments are similar to challenges faced in evaluating such investments in other types of development projects. We have mentioned previously that evaluating the economic benefits of hard investments is relatively straightforward (although in practice it is not trivial) because a direct relationship can be constructed between inputs provided by the physical investment (i.e., water supply from a dam) and production output. Soft adaptation, on the other hand, is more complicated because the benefits, to a great extent, must be inferred from resulting changes in private sector behaviors and prices. Assumptions based on experience and informed judgment must be made about how specific interventions – e.g., agricultural innovations, training programs or policy reforms – could alter farmers' decision making, outputs and economic returns (see *Box 8* for methods for ex-ante evaluation of agricultural innovations).

With respect to costs, estimates can be made of the direct costs of undertaking both hard and soft interventions. Once again, costs of hard interventions are easier to compute (i.e., storehouses for food stocking or irrigation systems), while estimating costs of autonomous adaptation, as well as of planned, soft adaptations, is more challenging. In climate change impact studies in the agricultural sector, "albeit adaptation processes either autonomous or planned are considered among the main drivers of final climate change impacts on agriculture, they are mainly examined under the potential benefits rather than under the costs side" (Bosello and others 2007). The underlying rationale is that costs of adaptation measures that can be implemented autonomously by farmers (i.e., change in crops or calendar shifts), as well as of those measures that consist in policy incentives, are insignificant. Unfortunately, this assumption is only partly correct because, especially in developing countries, there can be significant transition costs in changing agricultural

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[8] With this method, probabilities for different events related to climate change are inferred by counting the number of models in which the event occurs (the methodology is described in Räisänen and Palmer 2001). Although in the literature some doubts exist regarding the theoretical foundations of this method (i.e., model runs may not be independent from each other), this technique has been applied in different studies, including the assessment of climate change impacts and adaptation solutions in the US Metropolitan East Coast region (Gornitz and Rosenzweig C. 2007).

BOX 8 ESTIMATING THE RATE OF ADOPTION OF AGRICULTURAL INNOVATIONS

Economic benefits of agricultural innovations require ex-ante insight into the likely rate of adoption. In order to estimate ex-ante what this rate might be, different dimensions that influence it must be analyzed. Generally speaking, adoption decisions depend on both sociological and economic factors. For example, Rogers (1962) suggests five dimensions (relative advantage, compatibility, complexity, divisibility and communicability), which determine the adoption rate.

Relative advantage relates to the extent to which a new technique or product is preferred to the existing technology. Generally, the superiority of an innovation is measured by its profitability (crucially dependent on assumptions on output prices) or risk-reducing potential. *Compatibility* is the extent to which a new innovation is consistent with existing norms, values and prior experience of prospective adopters. Also to be considered is the extent to which it is physically and managerially compatible with existing practices. *Complexity* is the extent to which new techniques and their consequences are easy or difficult to understand. In general, less complex ideas are more quickly and widely adopted. *Divisibility* is the extent to which an innovation can be used on a limited basis. The importance of divisibility stems from the potential risks involved in trying a new innovation. If trials can be done on a limited basis, earlier adopters, in particular, are able to limit their exposure to losses. Finally, *communicability* is the ease with which knowledge of an innovation can be passed along to potential users. This concept includes both the complexity of the innovation, as well as the rapidity and tangibility of benefits. Other important variables that may influence the rate of adoption are the *innovation's age,* the *initial investment* required by the adoption decision and the *riskiness of the undertaking* (Agriculture Canada 1984).

Operationally, one possible procedure for coming up with adoption rates is described in Lesser and others (1986). This procedure is based on questionnaires to potential adopters of a new technology and involves providing a sample of producers with facts about the effects of the product. Respondents are then asked a series of specific questions about their own plans based on the provided information. Potential diffusion rates are projected based on responses to a question like, "Overall, on how many hectares in your field would you expect to utilize technology x?" Moreover, respondents are asked when they plan to adopt the new technology, i.e., by choosing the most likely time between 6 months and 10 years from the innovation's availability. This approach can be applied in circumstances where respondents have no problems comprehending factual information of a hypothetical nature and responding to it in a meaningful way.

Source: Authors.

practices (including opportunity costs of time and/or travel costs for participating in training or other capacity building programs, irrespective of who actually bears such costs). In addition, new technologies might be required to make agriculture more climate-resilient (i.e., new seeds or water-saving irrigation devices). Hence, it is becoming increasingly important to get a grasp of adaptation costs to calculate the net benefits of adaptation.

BOX 9 DERIVING SOFT AND HARD ADAPTATION COSTS FOR IRRIGATION

To establish a range of global irrigation unit costs, the Economics of Adaptation to Climate Change (EACC) study team has undertaken a broad literature review of World Bank, Food and Agriculture Organization (FAO) and International Water Management Institute (IWMI) documents, project reports and meta-evaluations directly related to completed and ongoing irrigation projects. From these documents, the EACC team extracted project component costs and benefits into a database, which currently covers 622 projects in 66 countries.

The review process focused on extracting hard and soft irrigation costs. For each World Bank document reviewed, it was possible to disaggregate engineering (hard) and institutional (soft) costs, as well as identify the total number of hectares involved in the project. Engineering costs cover all project expenditures directly related to the physical construction, rehabilitation or modernization of an irrigation system. For example, land leveling, ditch construction and irrigation piping are all covered under engineering costs. On the other hand, institutional costs include all "soft" components of a project, such as water-user groups, trainings, irrigation management staff training or farmer capacity building. Unit costs have been calculated by dividing the investment costs by the total land area affected by the project (see Table 2).

TABLE 2 DISAGGREGATED UNIT COSTS

		Unit Costs	
Region	**Statistic**	**Institutional Development**	**Engineering**
Africa	mean	7,761.00	2,792.78
	std. dev.	15,224.92	3,145.88
	obs.	7	9
EAP	mean	161.29	750.22
	std. dev.	202.95	616.28
	obs.	7	9
ECA	mean	83.20	883.43
	std. dev.	55.80	1,148.39
	obs.	5	7
LAC	mean	2,991.00	2,125.82
	std. dev.	4,871.19	1,579.02
	obs.	10	11
MENA	mean	619.71	2,663.33
	std. dev.	524.45	3,690.43
	obs.	7	9
S. Asia	mean	454.13	2,401.27
	std. dev.	790.01	3,577.98
	obs.	8	11
Total	mean	2,130.75	1,997.13
	std. dev.	6,693.47	2,650.48
	obs.	44	56

This information will then be used to estimate needed investments in irrigation to adapt to climate change. A methodology is being developed to estimate irrigation needs following changed climatic conditions worldwide by using the IMPACT model (International Food Policy Research Institute). The related investment costs for hard and soft interventions will be derived by multiplying the area in need for irrigation by the historical cost, differentiated by region.

Source: Essam 2009.

For these purposes, different methods can be applied. One approach consists of piggybacking the costs of adaptation measures from an in-depth analysis of the documentation of past projects that financed the same types of interventions, which would be needed for adaptation purposes (i.e., irrigation, agricultural extension, flood protection, etc.). Unit costs can then be applied to additional investments needed to adapt to climate change, estimated by means

BOX 10 ELICITING ADAPTATION COST INFORMATION FROM LOCAL COMMUNITIES AND INSTITUTIONS

The Costing Adaptation through Local Institutions (CALI) project seeks to identify the perceived costs of adaptation options in rural areas from the perspectives of both rural households and the institutions through which the adaptation options are channeled. Four types of data collection methods, including household questionnaires, focus group discussions, institutional stakeholder interviews and expert interviews, are utilized.

For households, the study assesses ranges of past costs for households to adapt their strategies to climate-related hazards. For institutions, the amount of money and resources used in order to perform their tasks to assist households in adapting to particular hazards is assessed. These estimates serve as a basis for judging how much investments or aid would be needed from governments or donors to promote particular adaptation interventions in rural areas. In both cases, the information collected through stakeholder interviews is cross checked with information from the focus group discussions and expert interviews.

Since for most respondents, assessing the actual costs related to adaptation options is difficult, participatory appraisal methods are applied. In particular, the respondents are asked to allocate a fictitious income over different adaptation options by, for example, asking them to divide a number of coins or stones over a number of cups. This method provides two insights. First, more units are allocated to the more expensive than to the cheaper options. Thus, the number of tokens provides an estimate of the cost of the different adaptation options as perceived by rural households. The monetary value of a token can be determined by comparing actual prices of the adaptation options for which the prices are known with the number of tokens allocated to these options. In this way, to what extent perceptions differ from reality can be verified, offering a possible explanation on why particular options may or may not be adopted. This also allows for estimating the perceived monetary value of the options for which no market prices are known. Second, it forces respondents to rank the options, showing which options are considered more “valuable” than others, providing information on the perceived economic benefits of different options.

On the basis of the data collected through the questionnaires and interviews, an econometric and statistical analysis is performed to identify the cost elements of the different adaptation strategies. The costing framework used for this purpose indicates which costs have to be made in order to implement the different options, according to the following typology:

- household monetary costs;
- household labor requirements;
- household training requirements;
- required help from the community;
- required help from institutions, such as authorities or NGOs; and
- monetary needs of institutions, which are necessary to implement work.

Source: Agrawal, Kononen, and Perrin 2009.

of specialized models or expert judgment. For example, a review of irrigation projects, undertaken as part of a broad study on the Economics of Adaptation to Climate Change (World Bank, forthcoming), has come up with ranges of investments per hectare for this specific hard adaptation measure (see *Box 9*).

A second possible approach is based on the solicitation of information directly from local communities that are vulnerable to climatic risks and that take adaptation-relevant decisions. An interesting methodology, based on participatory appraisal methods, is presented in *Box 10*.

As previously noted, estimating costs and benefits of adaptation may be complicated by: (i) challenges in measuring *additional* costs and benefits of adaptation compared to development activities without the element of adaptation, when the project is not stand-alone; (ii) the difficulty in identifying the *co-benefits* of adaptation in stand-alone projects; (iii) debate over which *discount rate* to use, particularly when adaptation is expected to have long-term effects; and (iv) the high level of uncertainty in evaluating costs and benefits of adaptation due to uncertain future climate change and related impacts. The first three issues are discussed below, while the other major challenge related to uncertainty is discussed in Section 3.2.

(i) Evaluating additional costs and benefits of adaptation

In the case of no-regret adaptation investments and of broader development projects that fully integrate adaptation into their design, "adaptation actions are embedded within responses undertaken by private and public actors to a broader set of social and environmental stimuli. For example, farming practices, land use planning and infrastructure design might all reflect some considerations of current and anticipated climate, but it may not be feasible to isolate the costs and benefits of the climate component, as such decisions are also simultaneously conditioned by a whole range of other factors" (Agrawala and Fankhauser 2008). While it might be possible, in principle, to consider a hypothetical alternative project designed with less adaptation integrated into it, such an effort would have little meaning and it will be more valuable to compare alternative project designs *per se.*[9]

For stand-alone adaptation projects or projects with a distinct adaptation component included, additionality of costs and benefits of adaptation may be useful to estimate in some cases. This can be important, particularly when alternative project designs exist with different benefits and costs that can then be compared. One also can attempt to indirectly identify the costs of an adaptation activity linked to an existing development project through a "gap analysis" to pin down which additional investments the adaptation project needs in order to increase its resilience to climate change by a certain degree (*Box 11*).

(ii) Evaluating co-benefits of adaptation

A project designed for other purposes may also deliver increased climate change resilience as a co-benefit, even without a specifically identified adaptation component. For example, improved water management may add to yields in the near term and generate additional value in the longer term by reducing climate-related risks if climate change is expected to decrease water supplies or make them more erratic. In addition, adaptation activities themselves can yield co-benefits. For example, improved agricultural land management

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[9] If, for particular reasons, additional adaptation costs of an integrated project must be evaluated and the project design does not make it possible to directly identify them, one can try to make an educated guess of the percentage of project costs that can be allocated to adaptation. For example, the Integrated National Adaptation project in Colombia (World Bank 2006a) calculated the additional costs of adaptation by comparing the total project costs with the costs of existing projects with similar purposes implemented in the same areas, but without consideration of climate change.

BOX 11 CALCULATING ADDITIONAL ADAPTATION COSTS FOR IRRIGATION MODERNIZATION IN CHINA

The development objective of the “Mainstreaming Climate Change Adaptation in Irrigated Agriculture” project is to enhance adaptation to climate change in agriculture and irrigation water management practices through awareness raising, institutional and capacity strengthening, and demonstration activities in the Huang-Huai-Hai river plain (3H Basin) in China. The project is linked to an ongoing Irrigated Agriculture Intensification project (IAIL3), whose main components, including water saving in irrigation, drainage, and environmental protection in different agro-ecological zones, are important for adaptation to future climate change. However, IAIL3 components did not take climate change into account when designed, so that a number of vulnerabilities due to increasing climate variability and change must be addressed. The GEF/SCCF (Special Climate Change Fund) financed project has been designed as a gap-filling and programmatic operation that would focus on the 3H region with possible expansion to other regions as appropriate, based on initial experience with the project.

The project design was based on a preliminary gap analysis of IAIL3 from a climate change adaptation perspective. This approach allowed for clearly defining the baseline and additionality of the GEF project as follows.

Baseline Scenario

IAIL3 (the baseline project) finances sustainable development of modem irrigated agriculture in five project provinces in the 3H Basin, with the following development objectives: (a) increasing water and agricultural productivity in low and medium yield farm land areas; (b) raising farmers’ income and strengthening their competitive capacity; and (c) demonstrating and promoting sustainable participatory rural water resources and agroecological environmental management in the 3H Basin.

Summary of the IAIL3 “Adaptation Gap Analysis”

A number of specific weaknesses in IAIL3 with regard to climate change have been identified, including the following:

(a) Public awareness of issues relating to adaptation to climate change is very limited, as is the understanding and capacity of staff, officials and decision makers regarding climate change and adaptation.
(b) In the design of water saving works, the concept of collecting and storing natural precipitation was not integrated with irrigation and drainage works and there are few, if any, works and facilities in the field to collect and store rainfall runoff for more effective use of available rainfall.
(c) Some agricultural measures for climate change adaptation have not been fully considered, such as planting nitrogen fixation crops, adjusting sowing times of double cropped areas, staggered maturity of crops to reduce peak water demand and the more widespread development of agriculture facilities, such as greenhouses.
(d) Farmer and water-user associations are weak and have only limited ability to popularize new varieties, practices and technologies, which are better adapted to climate change.

(*continued*)

(*Box 11 continued*)

Alternative (GEF/SCCF Project Enhancement of IAIL3)

The GEF/SCCF climate change adaptation project will increase IAIL3 sustainability and, more broadly, the resilience of Chinese irrigated agriculture in the face of climate change, and support global environmental objectives. Specifically, the project focuses on those IAIL3 activities that were identified as being at risk from climate change.

The GEF/SCCF project will review and refine the original IAIL3 technical design for all adaptation-related activities and adjust the IAIL3 Project Implementation Plan to respond to the effects of both short-term climate variability, as well as long-term climate change in each region.

Financing arrangements

Due to the gap-filling approach in designing this project, the totality of project costs, estimated at US$55.5 million, can be considered "additional adaptation costs". Nevertheless, the total costs were further divided into two parts: (a) US$50.5 million, cofunded under the ongoing IAIL3 Project, to increase resilience of those activities that are potentially most affected by climate change; and (b) US$5 million, funded by GEF/SCCF, to support additional adaptation activities not directly linked to the baseline project, namely:

- identification and prioritization of adaptation options;
- demonstration and implementation of adaptation measures; and
- mainstreaming adaptation into national programs and institutional strengthening.

Source: World Bank 2008c.

practices to prepare for climate change can also lead to reduced erosion/siltation and carbon sequestration.[10]

Co-benefits become particularly important in the economic evaluation if they otherwise would not be reflected in the project appraisal. This is typically the case if the co-benefits have the nature of public goods. A private investment in improved water management for agriculture, for example, can yield a stream of "private" benefits, including the reduction of farmers' longer-term, climate-related risks (adaptation co-benefit). Additionally, such investments may also convey "public" benefits for other categories of users (e.g., municipalities). Estimates of these co-benefits can be included and strengthen the overall case for the project.

(iii) Choosing the discount rate for evaluating longer-lived adaptation benefits

As noted, the appropriate discount rate to apply in benefit-cost analysis is one of the most often-debated topics in economics, regardless of the project's anticipated economic life. Concerns have been raised about the evaluation of long-term net benefits, more specifically, in the literature on climate change economics. Two distinct arguments have been advanced for using a "special" approach to discounting in this case, one that

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[10] Some also may entail negative spillovers (e.g., increased irrigation upstream may limit water availability downstream).

does not make long-term benefits of limited consequence in the economic calculus.

The first argument is related to intergenerational distributional equity: a high discount rate can trivialize the potential value of a long-term climate adaptation investment for the well-being of future generations (for example, see Stern 2007). The counterargument is that applying such a special discounting procedure to certain classes of investments, but not others, distorts the allocation of scarce resources among investments with different future benefit streams, even to the point of crowding out alternative investments with large near-term benefits.[11]

The other argument is connected to uncertainty over long-term future rates of return, which is addressed in Section 3.2.3. The argument is usually framed in terms of economy-wide impacts of policies or investments on future economic growth and well-being. Suppose that a long-term adaptation activity has a particular expected flow of net benefits over time, but the actual flow could be above or below the expected net benefit stream because of uncertainty about the magnitude of adverse impacts of climate change. If climate change impacts are more severe than expected, economic growth will be more adversely affected. However, this situation also occurs when the benefit stream from adaptation is more likely to be particularly large. Thus, the adaptation activity delivers both an expected stream of its own benefits, and a reduction in the long-term variability of total income and well-being. This second benefit is what is known in the finance literature as a risk-reduction premium. In some cases, it can have an impact on evaluation similar to using a lower effective discount rate, with the size of the reduction depending on the extent of uncertainty, among other factors.[12]

These arguments at the level of the economy as a whole have limited direct relevance to valuing individual adaptation projects. However, two other observations broaden their potential relevance. The conclusion above is not that uncertainty should lead to an adjustment in the discount rate; rather, it is that any broader risk-reduction benefits should be incorporated in assessing an adaptation project's value. Moreover, in principle, these risk-reduction benefits could arise in the near term as well as in the longer term.

Thus, we can first recommend that whatever discount rate is used for other projects in a particular country or region should also be the default rate for adaptation projects, with exceptions made sparingly on a case-by-case basis. In assessing the benefits of a project, however, attention should be paid to the possibility that the project will help smooth out fluctuations in overall well-being from climate change, as well as provide more direct benefits. Such impacts are likely to be difficult to quantify, but it is useful at least to identify them heuristically. Realizing such benefits still requires that a project be "large enough" relative to total output and economic well-being that its success can have more than a trivial effect on these aggregate variables.

Arguments for using lower longer-term discount rates based on intergenerational equity require that the project has significant value to the well-being of future generations, and that few, if any, alternative investments can accomplish this end. For most adaptation projects, this condition is unlikely to be met. Use of lower longer-term

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[11] One suggestion to avoid such distortion is to apply, to all long-term projects, an annual discount rate that declines over time (referred to as "hyperbolic" discounting). However, this approach is still being debated in economics literature.

[12] An illustrative example is provided in Pindyck (2007); see also Howarth (2003) and Weitzman (2004).

discount rates in this context should be limited to those large-scale and long-impact projects that meet the conditions sketched above. In principle, concern for the well-being of future generations are better addressed in the project assessment by considering the tradeoffs and ethical constraints that individuals are prepared to address in the present.[13] A more conventional present-value calculation would show how sensitive the evaluation might be to the valuation of long-term benefits; this information can help decision makers form judgments regarding the emphasis that intergenerational concerns might be given in project selection.

3.2.2 A NON-ECONOMIC ASSESSMENT APPROACH—MULTI-CRITERIA DECISION ANALYSIS

Often, decision makers need or want to evaluate alternatives across a range of different and potentially incommensurate criteria. This is especially true in the context of agriculture and climate change, where an adaptation project can help reduce the negative effects of climate change on a number of social, environmental and economic indicators. There also may be many instances, as already noted, when information on the monetary value of potential benefits or their likelihood of being realized is scarce and significant amounts of informed judgment must be substituted[14]. In such cases, multi-criteria decision analysis (MCDA) can be useful.

Similar to the economic analysis methods, MCDA is a utility-based approach, where the "best" alternative is the one that results in the most preferred probability-weighted outcome (Kenney and Raiffa 1993; Morgan and Henrion 1990). MCDA has taken many forms, but each approach has the same general steps:

- Identify the broad objective of the decision maker and operationalize it through multiple qualitative and quantitative criteria, which need to be both comprehensive and measurable (Kenney and Raiffa 1993).
- Assign weights to decision criteria based on the decision maker's subjective preferences. This can be done in a participatory setting, by eliciting the subjective preferences of stakeholders and trying to reach a common set of weights among different stakeholders through a consensus-reaching process led by a facilitator.
- Identify the utility function as a function of decision criteria and their associated weights. It is common to assume a linear and additive function, but other functional forms are possible as well (Kenney and Raiffa 1993).
- Identify the alternatives to be considered.
- Identify likely states of the world in which the alternatives might play out and the likelihood of those states. This can be based on empirics or expert judgments (e.g., the Delphi method, see Dalkey 1969, and Kenney and Raiffa 1993).
- Estimate the payoffs of the alternatives for each state.
- Choose the alternative with the preferred outcome (i.e., maximum expected utility).

This method helps decision makers structure complicated problems and systematically evaluate alternatives. Other advantages include the fact that the method is easy to administer and transparent, and allows for active involvement by

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[13] For more detailed consideration of these and other issues related to discounting, see Portney and Weyant (1999).

[14] For example, in gauging the impact of climate change on ecosystem services and the benefits of adaptation measures (i.e., to combat land degradation), one approach might be to conduct structured interviews with affected local citizens who collectively could possess a great deal of qualitative information on how prior changes in ecosystem conditions affected productivity. This may be more useful than seeking to directly gauge an economic value of avoided ecosystem damages through survey-based methods.

diverse participants and for qualitative values. Clearly, this method relies heavily on individual judgments and subjective probability assessments. In judging its potential applicability, one needs to consider how explicit decision makers are about their objectives and values, and the consequences, if a lack of consensus exists among the various stakeholders. *Box 12* discusses the application of a simplified form of MCDA for identifying and evaluating adaptation options in three Latin American countries.

3.2.3 DEALING WITH UNCERTAINTY

We have already noted how environmental, technical and economic uncertainties permeate the evaluation of climate change adaptation. Economic evaluation with uncertainty usually considers scenarios judged to have various degrees of likelihood. For example, "high impact" and "low impact" scenarios implicitly are deemed less likely than an "anticipated impact" scenario. More sophisticated extensions of this approach will postulate explicit probability distributions for key factors, construct an implied distribution of results (in terms of NPV), and examine the mean (or median) and variability of the net benefits.

There are three drawbacks to these approaches when evaluating adaptation. First, they assume knowledge of probabilities about which we may in fact know fairly little. Second, they typically treat probabilities as given, when the purpose of some adaptation is to reduce risks (defined as the probability of occurrence of threatening events). Finally, they do not incorporate the possibility of decisions that would, as in real life, unfold over time as circumstances change and new knowledge is gained. In such conditions, there is, in fact, an economic value to being able to maintain a larger set of options, over and above whatever expected NPV would be calculated in scenario-based approaches.

In this section, we examine three alternative approaches to deal with uncertainty. First, we return to the use of probabilistic methods, which can be used for addressing reduction in risks from extreme events. We then discuss "real option analysis," which reflects the state of the art in economic evaluation under uncertainty, but, thus far, remains difficult to apply in concrete cases. Finally, we take up "robust decision making," an approach based on more heuristic evaluation methods, but able to be applied even in situations of high uncertainty over future states of the world. Each of these approaches addresses some of the abovementioned limitations, but none addresses all of them. In drawing our conclusions in Section 4, we offer a few specific suggestions on how to address uncertainty in evaluating adaptation when practically available methods and data are limited.

(i) Cost-benefit analysis of risk reductions

For some adaptation initiatives, it may suffice to be able to economically evaluate how the project reduces risks and expected monetary losses associated with an uncertain adverse agricultural impact. This might be the case, for example, when the impacts from climatic extremes are a primary concern. As noted in Section 3.1.3, work in the field of disaster risk reduction suggests some potential approaches along these lines (Proventium Consortium 2008b). Just as one can assess, with this method, the ways that climate change might alter the probabilities and expected consequences of impacts of varying size and frequency, one can examine how these factors might be reduced by different resilience-increasing interventions (e.g., stronger flood protection) and compare that to the cost of the interventions.

This method is better suited to disaster-oriented adaptations versus adaptation to less extreme climate change impacts. Aside from the problem of estimating probabilities already noted, one challenge with this approach is how to identify

BOX 12 MULTI-CRITERIA PRIORITY SETTING FOR ADAPTATION DECISIONS IN LATIN AMERICA

The focus of this study — carried out in three Latin American countries with very different agro-climatic and socioeconomic characteristics — was on identifying relevant climate changes in selected agro-ecosystems in Latin America, and formulating adaptive response options that can be used to develop local action plans, which will, in turn, support informed responses in the future. The study adopted a "bottom-up" approach, in which response options were identified and prioritized by local stakeholders. This approach was chosen because it maximizes the likelihood that the adaptation measures, which are ultimately chosen, will be realistic and feasible to those who are familiar with local circumstances and will make resource management decisions. In a series of three workshops and intervening work by local teams in each country, local stakeholders – farmers, farmer organization representatives, agronomists and technical experts, extensionists and other stakeholders – were closely involved in:

- Identifying current climate changes and their implications for local agricultural systems, rural livelihoods and local people.
- Identifying possible response options – technical, institutional and policy – to support local adaptation strategies to climate change.
- Prioritizing these possible response options in the form of activities and initiatives that will form local action plans.

A formal priority-setting methodology, very similar to a MCDA approach, was used to establish priorities among alternative adaptation options. The completion of the prioritization exercise involved three components:

1. Identification and weighting of a number of criteria: workshop participants in each country were asked to allocate 100 points among eight impact criteria and another 100 points among six viability criteria.
2. Elaboration of the characteristics of each response option: "profiles" of each of the response options identified by stakeholders were developed, including information on: (i) the underlying need for the response option; (ii) technical characteristics; and (iii) a rough indication of costs and benefits.
3. Assigning values to each of the criteria as applied to each of the response options in order to generate a final prioritized ranking of the options: participants were given a matrix and asked to assign a value from 1 to 10 based on the extent to which they believed each criterion was effectively addressed by each response option. The participants' ratings of each response option were then weighted by criteria weights previously elicited; the impact criteria were proportionately assigned 50% of the overall score, while the other 50% was assigned proportionately to the viability criteria. As a result, a ranking of adaptation options was obtained.

Source: World Bank 2009c.

potential autonomous adaptations and their impacts on the benefits of the planned adaptation initiatives. Influences of autonomous adaptation would have to be specifically incorporated into the "risk-exceedance" curves discussed in 3.1.3.

(ii) Real option analysis

The real option methodology is based on the idea that some investment projects can be evaluated as a set of compound options. Just as a financial option is defined as the ability, but not the obligation, to buy or sell an underlying security at a fixed price, a real option can be defined as the ability to undertake a future economic action or project. An adaptation measure may maintain existing options or even create additional ones. For example, a water management project may help a community to preserve the option of remaining in place rather than migrating if future climate change makes local livelihoods infeasible. Even though it is not possible to know in advance the severity of future climate change or the ability of the investment to forestall relocation, the project provides a choice that otherwise would not be available.

Because an investment often commits scarce resources in an irreversible way under uncertainty, another option for the decision maker to consider is whether to undertake a project now or to wait. Once the project has been implemented and the investment cost has become a "sunk cost," the waiting option is eliminated. The economic value of waiting can, in principle, be calculated and compared to the economic value of the project (net of the waiting option value). Thus, option value considerations can affect the timing, as well as the nature and scale, of adaptation initiatives.

Real option analysis makes it possible to extend the standard NPV methodology through combining traditional cost-benefit analysis under uncertainty with value estimates of the real options created and destroyed by the project. This approach is particularly useful for:

- Evaluating investments under dynamic uncertainty, i.e., investments whose value is highly sensitive to uncertainty over the future state of the world, and where the degree of uncertainty may vary (generally decrease) with time.
- Evaluating investment decisions that can be phased, i.e., when decisions such as making a certain investment, scaling up the project, abandoning the project or switching to different activities can be delayed to a future time (Knudsen and Scandizzo, 2004), such as when more information on climate change impacts and on consequences of different project alternatives becomes available.
- Taking into account different irreversibilities (in future world conditions, as in certain types of climate change impacts, and in the range of future choices determined by current investment decisions) and future options that are conditioned by present choices (Ambrosi, 2004).

As indicated above, a number of adaptation projects can be considered natural candidates for the application of this methodology, since:

1. their economic value crucially depends on the future state of the climate, which is unknown when the decision to undertake a project is made;
2. irreversible impacts may materialize in the future if no action is taken today to prevent this from happening (i.e., desertification of agricultural land);
3. some investments, especially in infrastructure, can be considered irreversible in the sense of locking in capital for decades (i.e., a water reservoir of a predetermined capacity);

4. phased projects constitute a common and reasonable choice, when it is recognized that learning during the initial phase of the project will allow improving project design for subsequent phases, which is often the case in new development fields, such as adaptation to climate change; and
5. adaptation investments are meant to create future options for its beneficiaries (i.e., capacity building on drought resistant crops, water harvesting techniques, use of seasonal climate forecasts, or alternative livelihoods to agriculture are examples of soft adaptations that generate a sustained livelihood/climate resilience option for farmers in the future).

Evaluating a project through real option analysis can also be considered as a new form of risk analysis, where risk is identified both positively, as the contingent wealth of opportunities created by the project, and as a cost, in terms of the contingent liabilities that the project may generate (Scandizzo 2008). One example is in the form of threats generated by future climatic conditions, which are different from ex-ante projected rainfall data on the project area. An important element of project evaluation through real option analysis is thus the estimate of risk, which may be counteracted by project actions, whose costs are also evaluated. This form of risk analysis therefore takes the form of an examination of the project structure, and a largely qualitative appraisal of assets and liabilities corresponding to a number of project alternatives. Such a process leads to the identification of those alternatives, which increases the likelihood of project success in the context of uncertainty. As a consequence, evaluation becomes an interactive and constructive task, particularly in the early phases of project preparation.

Hence, real option evaluation involves recognizing and identifying capabilities and opportunities created or destroyed as a consequence of project adoption, beyond the standard cash flows considered by the NPV approach. The economic value of the project is calculated by adding the value of the options created by the project (i.e., option to adapt, to abandon, to scale up, etc.) and subtracting the options destroyed by the project (i.e., option to wait or to make an alternative investment) to the standard NPV (Knudsen and Scandizzo 2004). As a consequence, a positive "extended NPV" result is an indication that the project is economically viable even if the standard NPV is negative (*Box 13, Figure 3*).

Investment evaluation according to real option analysis can be done according to two different technical procedures, namely the decision tree analysis and the binomial analysis. The main problem associated with the option evaluation methods is that they require estimating probabilities associated with future outcomes. When this cannot be done based on scientific grounds, such as in the case of climate change, subjective probabilities are solicited through stakeholder consultations, by identifying possible future scenarios and assessing the likelihood of each, according to the stakeholders' viewpoints. Given the crucial importance of probabilities in determining the economic value of the project, a main pitfall of this approach is the reliability on subjective probabilities. On the other hand, the participatory process of scenario creation and evaluation facilitates the identification of a flexible project design that expands the capabilities to deal with climate variability and change, especially for the poor (Scandizzo 2008).

Because of the constructive nature of evaluation, a full application of real option analysis requires engaging the methodology along the entire project cycle, from the very beginning of project conception and design. In general, in order to identify and evaluate the options within a project, the following three steps are necessary (Scandizzo 2008):

BOX 13 APPLICATION OF REAL OPTION ANALYSIS TO AN IRRIGATION PROJECT IN MEXICO

A case study on an adaptation project in the agricultural sector in Mexico has been conducted to show the potential of applying real option analysis for the evaluation of adaptation to climate change. The development objective of the Rio Conchos Basin project is to improve the efficiency of irrigation water use, thus promoting no-regret adaptation to climate change in irrigated agriculture. One of the project's components is the modernization of the existing irrigation infrastructure.

The irrigation modernization component alone would create economic benefits solely from water savings, estimated in US$5.6 million. The net present value (NPV) of the project, also considering operating costs, would be about US$25 million against investment costs of about US$317 million. Hence, this project component does not appear acceptable on traditional grounds, since the NPV is negative by US$292 million.

However, because of uncertainty and the possible impact of climate change, however, the analysis is extended to evaluate the adaptation options opened by this basic project. The most important of these options consists of the fact that fine tuning irrigation systems gives the opportunity to profitably extend cultivation to higher-value crops, if warranted by sufficiently favorable circumstances and provided that further investment is undertaken in the form of plant protection by plastic coverage (plasticulture). This "growth option" would create three major benefits respectively from water and energy savings and from increasing revenues.

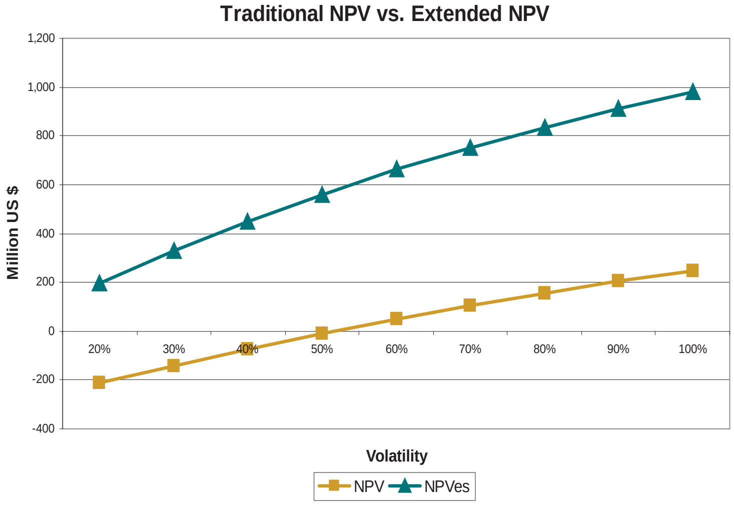
A more important way in which the project can help adaptation to climatic changes for the farmers of the project area is by reducing the threat of the lowering of the water table and the increasing danger of saline intrusion. This is a catastrophic threat linked to increasing aridity that climate change would be likely to cause. Even though irrecoverable damages to the water table would occur for natural causes, these contingent damages correspond to a "liability option," held by an impersonal agent (e.g., Mother Nature). Its value can be estimated as that of an option to significantly reduce or even destroy farmers' income (the underlying asset). The underlying asset of such an option is the opportunity cost of the water saved with the implementation of the basic project plus the value of the adaptation option (because they would both be lost if the water table were contaminated). The value of the strike, on the other hand, is the threshold of water utilization (in terms of its economic value) at which it is reasonable to expect that water contamination would occur.

Figure 3 summarizes the results of the analysis, assuming different volatilities, i.e., degrees of uncertainty (x-axis). It shows that, despite a negative NPV for volatility < 50%, the project appears highly profitable on economic grounds, by virtue of its potential effect on active adaptation (the growth option), and also of its possible effectiveness in removing a liability option, which is a consequence of climate change.

(*continued*)

(*Box 13 continued*)

FIGURE 3 APPLICATION OF REAL OPTION TO AN IRRIGATION PROJECT IN MEXICO



Source: Scandizzo and Notaro (2008).

1. Identifying the options. This first step aims to determine the consequences of project implementation on the capabilities (i.e., higher capacity to respond to climate change) and opportunities (i.e., new technologies and/or possible favorable consequences of climate changes) of its stakeholders. This phase generally requires stakeholder involvement (i.e., through focus groups) in defining scenarios and identifying capabilities and options created by the project.

2. Analyzing the options. This second phase consists of:

- Designing the different components of the project, taking into account the results of the first phase, and identifying benefits and costs for the project's duration. This step is identical to a standard feasibility study based on the NPV method, and requires close collaboration of the team working on the real option analysis, the project team and other consultants who carry out project preparation studies.
- Assessing the opportunities and threats that climate change can generate, such as increases in aridity, changes in the level and distribution of precipitation, water contamination, changes in temperature throughout the year, increased likelihood of extreme meteorological events. Probabilities need to be assigned to future possible outcomes.
- Applying the option algorithms to calculate the option values. This step requires choosing among two alternative option evaluation methods, depending on the circumstances, and calculating the project value.

3. Evaluating the opportunity of acting on or exercising the option. This third phase is aimed at determining whether or not to "exercise the option". For example, if the

option under consideration is the option to wait, the assessment will indicate whether it is economically more efficient to implement the project (or a specific activity) now, or to wait for additional information about input or output data. The evaluation process should incorporate a sensitivity analysis to test the sensitivity of option values to the parameter estimates.

(iii) Robust decision making

All methods discussed above rest on some form of an expected benefit or utility analysis with a quantitative characterization of the uncertainties. In the context of climate change, however, often uncertainties are so profound that there is little information or consensus on what probability distributions to consider for input variables, how to rank alternatives and what scenarios to consider in the analysis. The term "deep uncertainty" has been used by Lempert and others (2003) to describe the situation where decision makers lack the knowledge or consensus about the system model that relates alternative courses of action to outputs of interest, distribution probabilities on the inputs to the system model, or value functions that rank the desirability of the outcomes of interest.

Robust decision making (RDM) can provide an alternative quantitative decision analytic method that avoids subjective probability assessments and scenario predictions (Lempert and others, 2003). In RDM, uncertainties are not framed with prespecified probability distributions over input parameters to the system model. Moreover, the future "states of the world" that are considered in the analysis are not limited to few subjective scenarios. Instead, RDM creates hundreds or thousands of plausible futures, in the judgment of the analyst, that are then used to systematically evaluate the performance of alternative actions (Bankes and others, 2001).

RDM is an iterative evaluation process. Once an ensemble of scenarios is generated, each alternative action can be systematically compared according to a range of criteria, as in MCDA. For example, adaptation efforts could be evaluated according to anticipated effects on yields given a climate scenario and an assumption about the productivity and cost of the intervention, the differential effects across different economic subgroups of farmers, and performance if climatic conditions turn out much worse than anticipated in the scenario under consideration.

Of particular interest is the identification for any given alternative action of the set of conditions where it performs poorly according to the various criteria, reflecting, again, the judgment of the decision maker. A "robust" alternative is one that, compared to other alternatives, performs reasonably well across a wide range of plausible futures. In other words, it is one whose payoff is insensitive to poorly characterized uncertainties (Lempert and others 2006).

A strong advantage of RDM over other methods for dealing with uncertainty is that it provides a means to evaluate alternatives even when there is lack of knowledge or disagreement on prior probabilities and benefit estimates. RDM also allows decision makers to make better informed tradeoffs in deciding on the desirability of alternatives (*Box 14*). The key disadvantage of RDM at this stage is that it is still a research tool requiring the use of complicated computer algorithms and software, as well as depending on the ability to construct a large range of plausible future scenarios from whatever information is available. Significant work will be needed to adapt this approach for use in evaluating specific projects.

BOX 14 RDM FOR ADAPTATION DECISIONS IN THE WATER SECTOR

The Inland Empire Utilities Agency (IEUA) is a water-supply agency in a rapidly growing area of southern California. Because of rapid population growth in an already dry area, IEUA confronts the prospect of major investments in acquiring additional water supplies and in replenishing groundwater through recycling. The prospects of climate change add to the complexity of the planning task. The effects of future climate change on precipitation and runoff in the IEUA area are uncertain; it is necessary to weigh the possibility of wetter than historical conditions with more natural recharge of aquifers, and hotter, dryer conditions with more rapid evaporation and less recharge.

An analysis of “robust” water management options for IEUA in the face of climate change uncertainty found that because the cost of water shortage was high if the latter conditions occurred, it made sense for the agency to invest in more water conservation as well as in recycling as a kind of hedge, if decision makers perceived the chance of those conditions to exceed 25 percent. This extra investment was not warranted when one evaluated alternative plans by their expected present value of net benefits, without factoring in hedging value. The approach taken in the study was highly interactive, with decision makers working in tandem with analysts to ascertain policy-relevant scenarios to consider and the costs of shortage.

Source: Groves and others 2008.

4. CONCLUSIONS

SOME BASIC STEPS FOR PROJECT-LEVEL ECONOMIC EVALUATION OF ADAPTATION

The main purpose of this paper was to discuss methodological options to assess the economic soundness of adaptation investments at the project level, with a focus on agriculture. The choice of specific approaches to evaluate a particular adaptation project will be dictated by the characteristics of the project, specific questions of interest, existence and accessibility of data, and skills of available experts. *Table 3* provides a summary of the main characteristics of the proposed methodological options.

Although time, budget and data limitations constitute obvious constraints in the use of the methods discussed (especially those involving more technically complex modeling, statistical assessments and/or probability calculations), they suggest concrete steps in assessment that, if applied early enough in project preparation, can be useful to inform project design (e.g., to select the most suitable crops to local climate conditions and management practices, or to design project components that are likely to maximize benefits for local communities according to their own judgment). In cases where the stakes are large in terms of project resilience, a higher budget than initially envisaged for preparatory activities and appraisal may pay significant dividends in improved project design. Options exist for employing simplified versions of some methodologies, as discussed below.

We propose below a series of steps for carrying out the economic analysis of an adaptation project, and discuss the potential utilization of the methodological options presented in this paper for project-level analysis. Many of the evaluation steps listed here (namely steps 3, 5, 6 and, eventually, 8), can greatly benefit from knowledge exchange with stakeholders.

1. Develop information on relevant climate risks for the project area and specify the temporal horizon of the analysis, clarifying, in particular, the extent to which the focus of the intervention is on dealing with increasing climate variability and extremes, or longer-term change in climatic mean values. Guidance on climate risk assessment can be found in World Bank (2009d).

2. Assess several possible without-project scenarios by estimating the impacts of different climate variability/climate change projections

on agricultural productivity and other relevant measures of output and benefit. The Ricardian approach has generally been better suited to country-scale assessments, while crop models may be more easily scaled to local-level analysis. Developments in the near future might both reduce the complexity of methods and increase their applicability to project-level analysis (*Box 15*).

3. Identify the types of adaptation projects (e.g., stand-alone or integrated within a broader development project), and possible adaptation measures (soft/hard) that the project could support and implement.
4. Estimate potential reductions in projected productivity losses (i.e., adaptation benefits) in with-project situations, under the same multiple scenarios used for examining the without-project case. Depending on the type of adaptation envisaged under the project, both crop and Ricardian models can be considered for estimating the effects of adaptation, but their different ways of accounting for autonomous and planned adaptation need to be factored into the choice of methodology. Although using the same approach applied to the without-project scenarios maintains consistency, it may also be possible to utilize different methods to evaluate the two cases (see *Box 6*), when the specific circumstances suggest that this is a better way of comparing with- and without-project scenarios (e.g., to better reflect impacts of autonomous adaptation).
5. Quantitatively and qualitatively assess, as appropriate, any co-benefits and negative

BOX 15 TOWARD A MORE STRAIGHTFORWARD APPLICATION OF RICARDIAN AND CROP MODELS TO PROJECT-LEVEL IMPACT ASSESSMENT

Ricardian analysis can already be applied to project-level assessment, when a Ricardian function, developed within a country-level study, can be utilized for estimating local impacts (i.e., the function's parameters estimated for the country remain the same as in the original study, while the value of the climatic variables and other control variables is substituted by local data). Additional research is needed to allow using Ricardian functions developed for other countries with similar characteristics (a sort of "benefit transfer" approach), in the absence of a study for the same country. An even coarser approach is to simply apply country-level impact estimates to the local level. Such estimates are readily available (Cline 2007), but their direct application is not recommended, as local topography and land use can greatly affect both how climate change will materialize and how these climatic changes will affect local productivity.

Two different directions of future research in crop modeling might help develop more readily applicable tools for local level analysis. First, a simplification of the models themselves and the development of a more user-friendly interface could constitute welcome advancements toward a more widespread application of these tools at local level, despite the obvious trade-off with the precision of results. Second, similarly to the Ricardian methods, possibilities of benefit transfer approaches between different areas with similar local characteristics should be explored. Benefit transfer for both Ricardian and crop model estimates would call for an easily accessible and user friendly database with enhanced features.

Source: Authors.

spillovers that the project may bring about compared to a non-project situation. Stakeholder consultations may be particularly useful at this step.

6. Consider opportunities that the project may create in the future (i.e., through knowledge development or capacity building), as well any options that the implementation of the project may destroy, and the effects that the project may have on autonomous adaptation and adaptive capacity.
7. Attempt some economic estimation of future options maintained or lost. Future research may make the application of real option theory easier; in the meantime, some insights can be gained by examining several scenarios with and without different choices available in order to get a rough idea of what, if any, options are more important to be maintained or created by the project.
8. Assess how different alternative project options perform under different climate scenarios, based on estimated adaptation costs and benefits from previous steps. Different approaches may be advisable depending on the types of adaptation measures:
    - A probabilistic benefit-cost approach may be useful if a primary focus is adaptation to extreme events.
    - For some types of soft adaptation or in other cases where monetization of benefits is especially challenging, a multi-criteria approach may be useful, though its subjectivity needs to be recognized and incorporated into the appraisal process (e.g., through participation of different evaluators).
9. "Stress-test" the project to identify particular investments and soft adaptation initiatives whose benefits are particularly vulnerable to changes in conditions, and investigate potential project modifications that can reduce vulnerability to climate and other future shocks.

TABLE 3 SUMMARY OF METHODOLOGIES

Methodology	Suitability of the methodology with respect to:					
	Economic evaluation at the project level	Evaluation of autonomous and planned adaptation	Evaluation of soft and hard adaptation	Increased climate variability/extremes and climate change	Modeling of uncertainty	Precision of results
Crop models	*High* if an economic module is integrated in the model.	*Medium* for both autonomous and planned adaptation: specific measures are decided by the analyst, with no reliance on empirical data.	*High* for both hard adaptation (i.e., increased water availability due to new dam) and soft adaptation (i.e., the effect of training can be modeled to some extent by assuming a change from suboptimal to optimal management practices).	*High* for both climate change (i.e., changes in average temperature and precipitation) and climate variability/extremes (can model the effects of droughts and, to some extent, floods).	*Medium* can simulate the effects of future climate scenarios through weather generators (Monte Carlo–type simulation).	*Medium*: although capable of generating very precise field-level yield estimates, crop models are affected by over-estimation of climate change impacts and either under- or over-estimation of the effects of adaptation (depending on the analyst's assumptions).

(*continued*)

(*Table 3 continued*)

Methodology	**Suitability of the methodology with respect to:**					
	Economic evaluation at the project level	**Evaluation of autonomous and planned adaptation**	**Evaluation of soft and hard adaptation**	**Increased climate variability/extremes and climate change**	**Modeling of uncertainty**	**Precision of results**
Ricardian method	*Medium*: the method is more suited for evaluation at the regional/country level, but application at the project level is possible if a Ricardian function has been estimated at the country level and local climatic variables can be substituted in the equation.	*High* for autonomous adaptation (i.e., crop switching, change in irrigation practices); medium to high for planned adaptation (i.e., new irrigation systems). Ricardian models are well suited to forecasting "without-project" scenarios, accounting for a comprehensive range of autonomous adaptation; the capacity to assess the impacts of planned adaptation depends on what kinds of explanatory variables are captured in the model.	*Medium to high* for both types, depending on what explanatory variables are in the model (see previous column).	*High* for climate change/climate variability; low to medium for climate extremes (i.e., recent applications have a built-in flood damage function).	*Low* accounted for only through different future climate scenarios.	Precision of results depends on the method (i.e., structural approaches accounting for agroecological zones are more precise) and on country characteristics (i.e., if a sufficiently wide range of climates already exist in the country, the impacts of climate change in a particular area are more easily estimable). Generally provides lower impact estimates than crop models since autonomous adaptation is built in.
MCDA	*Generally low* in current applications, but *possibly high*, if economic criteria (costs and benefits) are included among the decision criteria.	*High* for both, but more meaningful for planned.	*High* for both.	*High* for both.	*Medium*, through probability weighted scenarios.	Precision depends on how project performance with respect to each decision criterion is estimated: increasing precision from stakeholder-based, to expert-based, to model-based estimates.
Probability-based approach	*Low*: this method is more suited for evaluation of specific adaptation measures, not of a comprehensive project.	*High* for some planned adaptation measures (mainly hard). *Low* for soft adaptation.	*High* for hard, *low* for soft adaptation.	Potentially *high* for climate variability and extremes. *Low* for climate change.	*Currently low*, but *potentially high*, through probability distributions of climatic variables under future climate scenarios.	*Low* due to imprecise probability distributions (because of scarcity of empirical data on extremes) and uncertainties of future probabilities under climate change.

(*Table 3 continued*)

Methodology	Suitability of the methodology with respect to:					
	Economic evaluation at the project level	Evaluation of autonomous and planned adaptation	Evaluation of soft and hard adaptation	Increased climate variability/extremes and climate change	Modeling of uncertainty	Precision of results
Real Option Analysis	*High*, especially if the method is properly applied early in project preparation.	*High* for planned adaptation, including interventions that increase autonomous adaptive capacity.	*High* for hard interventions with irreversible investments. *Potentially high* for soft interventions.	*High* for both.	*Medium*: different future states of the world can be considered, with related (subjective) probabilities.	*Low* due to the many assumptions necessary to calculate the extended net present value (strike, volatility, value of underlying asset, etc.)
Robust Decision Making	*High:* can be scaled to projects of varying sizes.	*Medium to low for autonomous adaptation:* normally very reduced-form models are used to generate scenarios for assessment. *Medium* for planned adaptation	*Medium to high* for hard investments and *medium* for soft adaptation.	*High* for both.	*High*: representation of uncertainty is a critical element of the approach.	*Medium*: able to highlight vulnerabilities of different project plans but does not provide precise measures of payoffs.

Source: Authors.

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