# THE ECONOMICS OF ADAPTATION TO CLIMATE CHANGE

## METHODOLOGY REPORT

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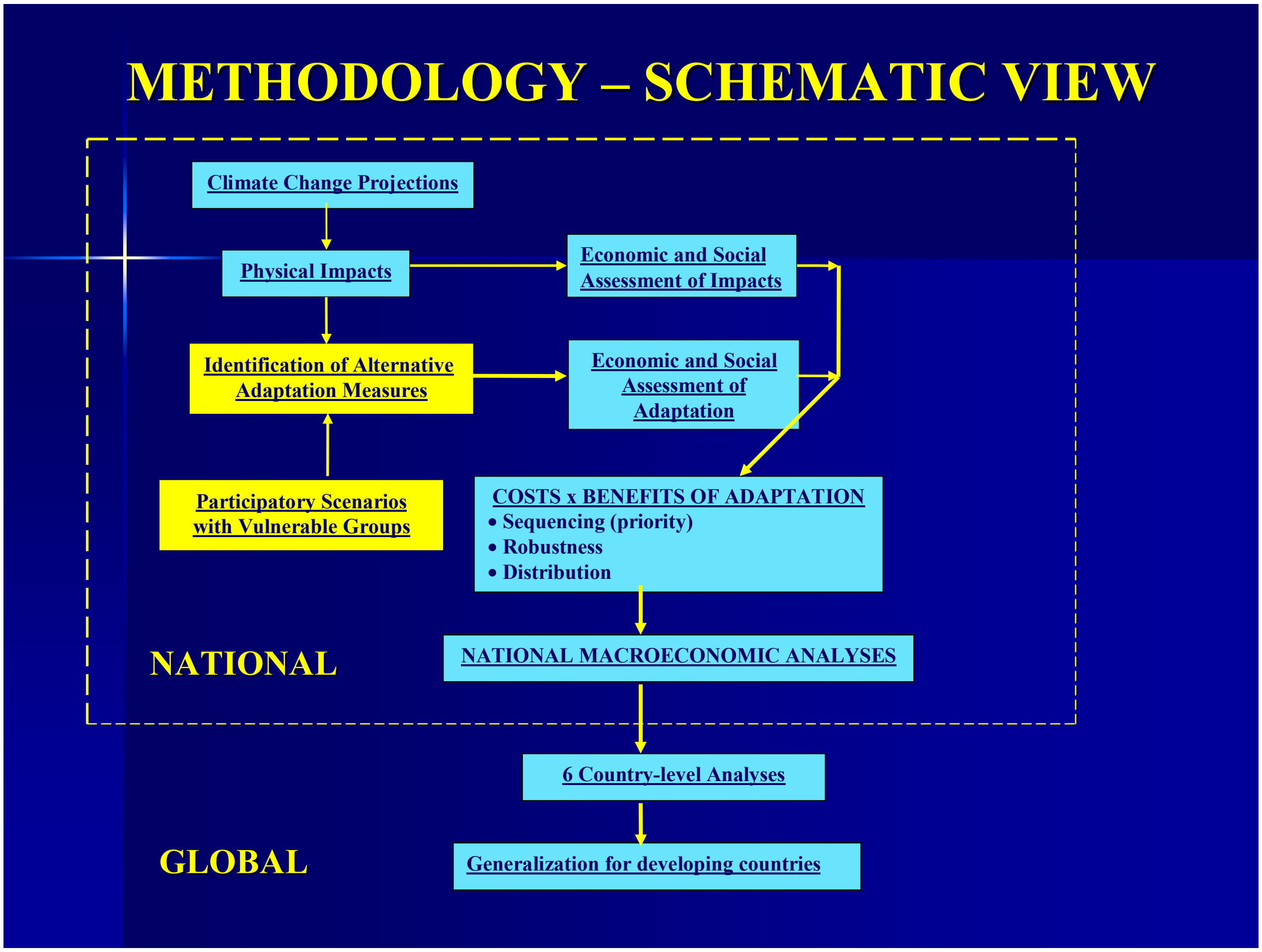
***Abstract of the Proposed Methodology***

*The foundation of the proposed methodology is a consistent downscaling of projected climatic changes from a multiplicity of General Circulation to local levels. Subsets of the suite of downscaled climatic factors are then to be used to estimate the vector of impacts on key economic sectors of each country, using sector-specific impact assessment models. Based on this information, alternative government adaptation projects will be specified and optimally chosen subject to a government budget constraint. Thereafter, direct impacts of climate change will serve as inputs into a macroeconomic framework to examine the indirect intersectoral impacts of climate change as well as adaption strategies. Finally, at each step the analysis will be complemented with perspectives and insights of people whose livelihoods are being or will be affected by changes in climate. Impacts of the climate change and the benefits of specific adaptation measures will be examined in the context of sub-populations defined by livelihood profiles. Local-level analysis of past and present autonomous adaptation measures for a range of groups stratified by sets of livelihood profiles will be conducted using participatory rural appraisal based primary fieldwork in addition to holding participatory workshops and consultations.*



## I. Background and Study Objectives

Current estimates of the costs of the likely impacts of climate change on developing countries and of the needed adaptation measures are in short supply, and the ones available are rather crude and simplistic. This is largely because the economics of adaptation to climate change is a new area of research and no agreed methodology to assess overall costs has as yet emerged. At the same time, an understanding of the full array of adaptation options, including institutional and policy changes, is crucial to prioritize the most effective adaptation strategies. Better estimates of the overall budget implications of implementing "climate-resilient development" are needed both to enable developing countries to implement their national development strategies and to inform discussions concerning possible international assistance. In order to fill these gaps, a partnership has been formed between the World Bank and the governments of the United Kingdom, the Netherlands, and Switzerland, in which the World Bank has been tasked with leading the technical aspects of the study to be funded by the three countries.

The study has two broad objectives. The first is to help decision makers in developing countries to better understand and assess the risks posed by climate change and to design strategies to adapt to it. This entails costing, prioritizing, sequencing, and integrating robust adaptation strategies into development plans and budgets. It also requires these strategies to deal explicitly with high uncertainty, potentially high future damages, and competing needs for investments in social and economic development.

The second objective of the study is to inform the international community's efforts, including the United Nations Framework Convention on Climate Change and the Bali Action Plan, to provide access to adequate, predictable, and sustainable support, and to provide new and additional resources to help developing countries meet adaptation costs, especially in supporting the most vulnerable.

It is important to note that these two objectives are somewhat at odds with each other. Supporting developing-country efforts to design adaptation strategies requires analyses at the more local level, incorporating country-specific characteristics and sociocultural and economic conditions. On the other hand, providing macro-level information to both rich and poor countries to support international negotiations and to identify the "overall costs" of adaptation to climate change involves a more aggregate analysis, leading to a trade-off with the capacity to focus on specificities of individual countries.

There is therefore a need to balance these twin objectives, since the approaches to achieve them are clearly different. The study's main focus will be dedicated to the first of the stated objectives, since only through a good understanding of local and sector analyses will it be possible to understand the more macro perspective. Nevertheless, the study will, in addition, link the microeconomic analyses with national, macroeconomic ones by using computable general equilibrium methods, and will estimate "overall costs" of adaptation by developing methods to extrapolate adaptation costs from a limited number of case study countries to all developing countries.

In particular, the study will build on learning from six country case studies covering a variety of environmental, social, cultural, and economic conditions, allowing for a degree of generalization and replication to most, if not all, developing-country contexts. These six countries are Bangladesh, Bolivia, Ethiopia, Ghana, Mozambique, and Vietnam. Furthermore, the study has been structured in two parallel phases, with the first informing the second. During Phase 1, a working methodology, presented in this report, has been developed and the scope of the analysis to be used in Phase 2 defined. During Phase 2, research and analysis at the country level will be carried out, drawing on both existing and new research in the six case study countries.

The methodology proposed in this report is meant to inform the country case studies of the most up-to-date approaches being utilized or being discussed in the literature to estimate potential impacts and costs of adaptation to climate change. Each country team is expected, however, to tailor the proposed methodology to the respective local context. Yet, in order to permit the extrapolation of adaptation costs from the six country case studies to all developing countries, it will be important to maintain a minimum commonality in the methodologies used across all cases.

Lastly, it is important to note that in most cases the report does not aim to identify a preferred or "optimum" approach to analyzing a problem, but rather to identify the pros and cons of alternative approaches and their suitability in different contexts. It also attempts to balance theoretical rigor with the need to tailor the work to developing countries that often face limitations of technical data and information as well as limited institutional capacity. In the same vein, the report tries to spell out situations where simplifying assumptions is called for in order to render the analyses useful for decision makers. In this sense, while maintaining the minimum methodological discipline necessary to ensure comparable and scalable results, the proposed methodology is firmly based on the principle that "the best is the enemy of the good."

## II. Peculiarities of the Economics of Adaptation to Climate Change

The idea that the global climate is changing, that humans and most living species will be directly and indirectly affected, and that they thus will be forced to adapt to new conditions is now fairly well accepted. This study's mandate is to examine the economics of this adaptation process. Although the overall concept may be simple, there are peculiarities of the problem that render it complex, or at least unique in terms of its economic assessment.

**Mitigation.** Though the focus of the study is on the economics of adaptation to climate change, it is important to recognize that any effective response to climate change will need to combine both mitigation and adaptation. While it is true that the greater the global effort to mitigate greenhouse gas emissions, the less will be the need to adapt to climate change, both mitigation and adaptation will be needed. On the one hand, it would be nearly impossible to adapt to some of the potential impacts of climate change, especially catastrophic impacts such as the loss of the West Antarctic ice-sheet and the implied five to fifteen meter sea-level rise, as well as irreversible damages to natural ecosystems. Mitigation is required to avoid these impacts. On the other hand, given that the world is locked into a certain amount of climate change even if countries began to drastically reduce greenhouse gas emissions with immediate effect, they will need to adapt to climate change as well.

Even though they are clearly complementary, mitigation and adaptation to climate change differ in important respects. For one, while the benefits from mitigation are expected to be global and deferred, those from investments in adaptation projects are expected to be local and to some extent more immediate. Consequently, while mitigation requires global collective action and thus the solution of immense political challenges, it is possible to address adaptation through local actions.

**Development.** The study of the economics of adaptation is complicated by the fact that adaptation is closely intertwined with development, making it hard conceptually and practically to distinguish development from adaptation.

The climate change literature has discussed a number of linkages between adaptation and development. For one, many believe that the best hope for adaptation to climate change is through economic development: development enables an economy to diversify and become less dependent on sectors such as agriculture that are more likely to be affected by climate change. Development also makes available greater resources that can be devoted to abating risk. Second, in many instances, development and adaptation are one and the same: making progress toward eradicating malaria will not only help achieve the Millennium Development Goals but also help societies adapt to increased malaria incidences that may be caused by climate change. Third, adaptation to climate change is seen as essential for development: unless agricultural societies adapt to changes in temperature and precipitation (for example, through changes in cropping patterns), their development will be stymied. Finally, adaptation will require a new type of development: urban development without adequate attention to drainage will exacerbate flooding caused by heavy rains. Similarly, since development is closely linked with greenhouse gas emissions and mitigation reduces the need to adapt, a new type of development that delinks growth from greenhouse gas emissions is needed. .

These linkages suggest that adaptation measures span the spectrum from discrete adaptation (defined as projects for which "adaptation to climate change is the primary objective),[1] to development-as-usual (defined as projects undertaken to achieve development objectives that also enhance climate resilience), to development-not-as-usual (defined as projects that carry the potential to exacerbate the impacts of climate change and therefore should not be undertaken). The implications for purposive intervention then vary from doing the same thing ('things' meaning policy and investment choices) or more of the same things, to doing different things, to doing things differently.

Any discussion on the relationship between adaptation and development also raises the issue of whether current development policies are enabling communities to cope with existing climate variability let alone deal with future projected variability. Every year, for example, millions of poor people suffer losses related to droughts, floods, and storm surges. The question that needs to be asked is whether some of these losses could have been reduced through specific policy measures, that is, whether there is an adaptation deficit.

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[1] World Resources Institute (WRI), *Weathering the Storm: Options for Framing Adaptation and Development*, ed. by Heather McGray, Anne Hammill, Rob Bradley, with E. Lisa Schipper and Jo-Ellen Parry (Washington, DC: WRI, 2007), p. 13.

It is important to note that the benchmark for assessing an eventual adaptation deficit should not be a utopian regime in which all agents are completely insulated from the damaging effects of climate-related events. No such regime will ever exist simply because it would be infinitely costly. What needs to be understood is, to the extent that a deficit exists, what types of barriers—financial, political, cultural, and institutional—are responsible for it. For example, are countries under-investing in irrigation infrastructure because of financial constraints or because of policies that under-price water? Similarly, are existing disaster management approaches driven by the fact that countries are only able to garner donor support for relief and reconstruction after a disaster occurs and not for risk reduction policies and investments? Understanding the nature of these constraints will help not only reduce the adaptation deficit but also make economies more climate resilient to future climate variability.

**Types of Adaptations.** Adaptation measures can also be classified by the types of economic agent that initiate the measure or by the timing of the measure, further adding to the complexity of the analysis. The existing literature distinguishes between autonomous or spontaneous adaptation, defined as adaptation by households and communities acting on their own without public-policy interventions but within an existing public-policy framework, and planned adaptation, defined as adaptation that is the result of a deliberate policy decision. Similarly, the literature distinguishes between proactive or anticipatory adaptation and reactive or ex-post adaptation, depending whether adaptation takes place before or after the impacts of climate change have been felt, respectively.

For the purpose of this study, such distinctions are not necessarily relevant because even spontaneous adaptation takes place in a context of given (current) government policies. Since our objective is to identify government policies (therefore to focus on planned adaptation) that provide the right incentives for private agents to adapt to climate change, efficiency and effectiveness criteria will dictate whether a proactive or a reactive policy is preferable, and whether it should be hard or soft in nature.[2]

By focusing on planned adaptation, the study does not in any way mean to suggest that autonomous adaptation is costless. However, given that the objective of the study is to help governments plan for risks, it is important to have an assessment of what problems private markets will solve on their own, how policies or investments can complement markets, and what measures are needed to protect public assets and vulnerable people—that is, an assessment of planned adaptation. Were the objective of the study instead to assess the value of mitigation efforts, it would be important to come up with a reasonable measure of overall adaptation costs including both planned and autonomous adaptation.

**Uncertainty.** Uncertainty is endemic to the problem of climate change and poses one of the biggest challenges to our study. There is a high degree of uncertainty regarding the extent and timing of the impact of climate change on the economy, how it will affect different groups and how these groups will respond, what the benefits and costs will be of planned adaptation

[2] Soft measures are policies such as regulations and standards, while hard measures include government building public infrastructure that induces private action—for example, the construction of roads or access to water and energy, which changes the economy of private agents indirectly.

measures, and how these factors will change over time. This makes it difficult to establish an "optimum" strategy *a priori*, since it creates uncertainty about what actions to implement and when to implement them. Should decision makers act now with limited information or should they wait until they have learned more about the potential impacts of climate change? Given the risk of a 100-year storm, should governments work to avoid Type I error (fail to build a sea wall and later be caught unprepared by the storm) or Type II error (build the sea wall early on, thus diverting resources from alternative social programs, and observe that the expected storms never occurred)?

Uncertainty about the various dimensions of adaptation to climate change can be dealt with using a risk management framework[3] This, first and foremost, requires that the uncertainty be described using multiple climate and non-climate scenarios. For each particular IPCC (Intergovernmental Panel on Climate Change) SRES (Special Report on Emissions) scenario, an ensemble of general circulation models (GCMs) provides a probability distribution for future climate variables (e.g., mean temperature and mean precipitation) as well as various indicators of extreme weather events (e.g., number of five-day precipitation periods and number of consecutive dry days). The potential impact of climate change and the costs and benefits of various adaptation measures then need to be assessed for a subset of these estimates—for example, a high-medium-low probability range of events—after which an optimum set of policies can be selected for each scenario based on the expected net benefits.[4] Thereafter, and across a range of IPCC scenarios, it is essential to seek robust strategies, that is, strategies that perform reasonably well compared to the alternatives across a wide range of plausible scenarios as well as strategies that can evolve over time in response to new information.

There is, however, another context in which uncertainty matters, namely low-probability but catastrophic-damage events. Many scholars have raised concerns about the appropriateness of cost-benefit analyses in such contexts. For example, the analysis by Weitzman[5] suggests that the marginal approach of cost-benefit analysis may not be appropriate for catastrophic events. Furthermore, given the inherent uncertainty about climate change, especially in the long-run, Weitzman established that such events ought to be the primary focus of policy makers, making their main concern "how much insurance to buy to offset the small chance of a ruinous catastrophe" (Weitzman, p. 705).[6] Weitzman's argument, however, is more likely to apply when determining the optimal level of mitigation of greenhouse gases at the global level, where the probability of an event that could destroy human life needs to be considered. But for the purposes of this study, the events whose damages are being reduced by most adaptation

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[3] UK Climate Impacts Programme (UKCIP), *Climate Adaptation: Risk, Uncertainty, and Decision-making*, ed. by Robert Willows and Ricenda Connell, UKCIP Technical Report (May 2003).

[4] Note that because the focus of the study is on planned adaptation, it is appropriate to consider net benefits as opposed to net utility as under planned adaptation risks will be spread over the entire population.

[5] Martin L. Weitzman, "A Review of the Stern Review on the Economics of Climate Change," *Journal of Economic Literature* XLV (September 2007), pp. 703–24.

[6] The Bank's Global Facility for Disaster Risk Reduction and Recovery (GFDRR) is currently developing a large study entitled "Assessment on the Economics of Disaster Risk Reduction (DRR)" jointly with the UN. A study component is looking precisely at the use of benefit-cost analysis in disaster risk reduction. The study is specifically looking at the applicability and drawbacks of using BCA in DRR from the theoretical, technical, and empirical perspectives. This study will greatly benefit from the insights originating for the DRR economic analysis and the two teams will be collaborating.

measures are local and not catastrophic in the above sense of the word. Consequently, there is little justification for abandoning the cost-benefit approach.

As for the timing of investments, this will to a large extent depend on the expected timing of the impacts of climate change on the economy. It will, however, also depend on (a) the effect of scientific and technological progress on the productivity of adaptation investment, (b) the effect of technological progress on reducing the uncertainty of climate change, (c) irreversibility in the costs of adaptation, (d) the social discount rate, and (e) considerations of cash flow and financing of a government's investment package. Waiting to build the seawall until greater knowledge concerning the frequency distribution of extreme events is known may be rational. If the rate of technological progress in sea wall design is also rapid, the argument in favor of waiting is even greater. And if the rate of social discount (or financing of the government's deficit) is high, the argument for waiting becomes stronger still.

Similarly, if the benefits of investments in adaptation projects are uncertain and there is a possibility of learning about these benefits in the future, then investments focused solely on adaptation ought to be delayed. For example, given that the benefits of investments in projects that help adapt to sea level rises are uncertain (largely because of the uncertainty in the extent of sea level rise) and given that some of this uncertainty will be resolved in the future, investments in sea walls should be delayed (though not necessarily eliminated). If it turns out that the rise in sea levels is not as high as previously expected, then investments made in sea walls could result in wasted resources, as once invested in sea walls these resources cannot to put to other use. On the other hand, investments in projects that both help adapt to climate change impacts and meet current development goals need not be delayed, despite the uncertainty. So, for example, investments in mangroves that help protect against the impact of sea level rises but also provide current development benefits need not be delayed. Were it to be that mangroves are not needed to adapt to climate change, resources invested in mangroves could still provide development benefits.

**Timeframe, Discounting, and Equity.** The choice of an appropriate timeframe for the analysis of adaptation to climate change is likely to affect some of the analyses and trade-offs between policies. Yet, some level of common sense is required in making such choice. Apart from the reliability of models and predictions, we consider it appropriate to use a timeframe up to 2050 (defined as the near term), and not beyond, for three main reasons: (a) forecasting climate change and its impacts on the economy become even more uncertain beyond this period; (b) most adaptation projects, with the exception of long-lived infrastructure, are unlikely to have a life that would extend beyond 2050; and (c) the complexity of the analysis, as discussed above, makes it prudent to get more precise estimates in the near term for an extended timeline.

The selection of an acceptable social discount rate is another critical factor determining what is "socially desirable" and thus the selection of policies. The timing of the realization of costs and benefits of projects is critical in this respect. If they are both realized over the near term, it is reasonable to apply discount rates as revealed by societies' preferences in allocating their consumption and investments.[7]

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[7] This would put the choice of the discount rate firmly in the "descriptive" rather than "prescriptive" camp. See K.J. Arrow, "Inter-generational Equity and the Rate of Discount in Long-term Social Investment," presented at

On the other hand, if project benefits affect not just the current generation but future generations as well, then the choice of the appropriate rate of discount becomes an ethical issue. Based on the famous Ramsey Rule ($r = \delta + \eta.g$, where r denotes the discount rate, $\delta$ the rate of pure time preference, $\eta$ the coefficient of relative risk aversion, and g the per capita growth rate of consumption)**,** according to which the social discount rate is equal to the sum of the pure rate of time preference and the coefficient of relative risk aversion times the per capita growth rate of consumption, the ethical issue comes down to a choice of two parameters—the rate of pure time preference and the coefficient of relative risk aversion. While a low value of the rate of pure time preference implies intergenerational equity, a high value of the coefficient of relative risk aversion implies equity over space and time. Thus for long-lived investments, and in the interest of consistency of methodology across country case studies, it may be best to resort to sensitivity analysis that allows for a range of discount rates rather than settling on one rate.

Finally, it is important to note that intra- and inter-generational equity concerns arise not only in the context of discounting but also in the contexts of (a) aggregation of costs and benefits when groups within a generation differ by income levels, and (b) appropriateness of cost-benefit analysis when the costs and benefits of a project are unequally distributed within a generation (or across generations). If, for example, the distribution of income in a society is considered to be unfair, then measurements of costs and benefits of a project could be corrected by weighting individual estimates by an equity factor or by assigning equity weights in aggregating from individual-level to project-level benefits and costs. The ethical judgment in such an aggregation process consists of the choice of the social welfare function used to aggregate individual cost-benefit estimates. Again, to maintain consistency, if equity weights are applied in the analysis, there is a need to conduct sensitivity analysis using a range of social welfare functions.

Another issue surrounding equity relates to the Kaldor-Hicks compensation principle, which states that if those benefiting from a project could, in principle, compensate the losers, and still gain in the net, then the cost-benefit criterion is satisfied.  There is a potential ethical concern here because no actual compensation need be paid by the gainers to the losers. While cost-benefit analysis remains a useful framework to guide the allocation of scarce public resources, this strongly suggests that policy makers should not be guided solely by the outcome of cost-benefit analyses. At the very least, this argues for paying careful attention to the distribution of the project's costs and benefits across socioeconomic groups, an approach adopted in this methodology report.

To sum up, in order to meet the twin objectives of the study, on the one hand, and to maintain tractability, on the other, the study is limited to the analysis of planned adaptation measures—although along the development spectrum and allowing for proactive and reactive adaptation. Also, the timeframe of the analysis is up to 2050, which limits, though does not eliminate, uncertainty inherent to climate change. This uncertainty, in turn, is to be dealt with using a risk management framework.

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the International Economic Association World Congress (December 1995). Available online: http://www-econ.stanford.edu/faculty/workp/swp97005.pdf.

## III. Operational Definition of Adaptation Costs

As with adaptation, the concept of adaptation costs appears correspondingly intuitive, being the costs required to adapt to climate change or, as defined by the IPCC, the costs of planning, preparing for, facilitating, and implementing adaptation measures, including transaction costs.

Though intuitive, the concept nonetheless is hard to operationalize. First, it is essential to define the level of adaptation. One possibility is to attempt to fully adapt, so that society is at least as well off as it was prior to climate change. Alternatively, one could choose to do nothing, that is, to suffer (or enjoy the benefits of) the full impact of climate change. Finally, and most interestingly, one would invest in adaptation using the same criteria as for other development projects and programs—and this could lead to either an improvement or deterioration in social welfare.

This discussion illustrates that the level up to which one wants to adapt is an economic problem—how to allocate one's budget to abating climate change while also meeting other societal needs. While this idea also remains simple and intuitive, in economic terms it poses significant quantification and measurement difficulties. A poor urban worker who lives in a fragile slum dwelling may find it difficult to decide between spending money to strengthen his/her hut (in order to adapt to more intense rainfall) or to buy school books or first-aid equipment for the family. Similarly, a poor rural peasant might find it difficult to choose between these basic needs and some form of simple irrigation that might compensate for increased temperatures and their impact on agricultural productivity. These examples suggest that the amount of adaptation desirable and the amount of adaptation feasible both depend on the level of income or amount of available resources. Of course, they also both depend on the expected impacts of climate change.

Further complicating the issue from the social planner's perspective is the notion that the amount of adaptation desirable depends on how much autonomous adaptation is already taking place: this affects how much government-induced adaptation is desirable. The extent of autonomous adaptation may, however, not be known to governments.

**Simple Definition.** In order to operationalize the definition of adaptation costs, consider two scenarios, one with and the other without climate change. In the case without climate change, or what we will refer to as the base case, assume the country has defined a set of investment projects—typically in its yearly budget which is prepared by a ministry of finance or planning—that maximizes social welfare. These are feasible projects given the available budget. For purposes of illustration, assume the projects selected have a benefit-cost ratio of at least 4 and that six projects are included in the current year's budget, of which three are climate related (P1, P2, and P3) and three are not (P4, P5, and P6).

Now consider the scenario with climate change. Climate change is likely to affect the economy in a number of ways, including relative prices (for example, the cost of food) as well as the benefits from various projects. An early warning system that was not economically justifiable in the base case may suddenly become viable and pass the benefit-cost ratio in the scenario with climate change. Consequently, the composition of the set of projects selected under the with-climate-change scenario is likely to be different than in the scenario without climate change. For most situations, it is reasonable to assume that projects P1, P2, and P3 will pass the minimum benefit-cost ratio test under the climate change scenario, and that they will thus be part of the set of projects selected under this scenario. To the extent that the costs of implementing P1, P2, and P3 remain the same across the two scenarios, these projects constitute no-regret adaptation measures.

At the same time, let us assume that P4, P5, and P6 no longer pass the benefit-cost ratio test, and two new projects—P7 and P8—are chosen instead. P7 or P8 could be the early warning system that did not pass the benefit-cost ratio test in the base case, but does in the case with climate change (as climate change is likely to increase the benefits of early warning systems). Because P4, P5, and P6 have been dropped, their benefits will also have disappeared.

The question then is what are the adaptation costs? In this simple example, one way to define these is as the costs of the projects selected under the with-climate-change scenario that would not have been chosen in the base case, that is, the costs of implementing P7 and P8. While these projects generate benefits equal to the avoided damages, they represent a cost to society that could instead be enjoying the benefits from projects P4, P5, and P6 had climate not changed. This is the same as the situation of the urban worker who has to invest in the protection of his house, or the farmer who has to invest in irrigation, both giving up their potential investments in books and medication. Note also that no-regret projects do not result in adaptation costs, insofar as the costs of these projects do not vary between the with and without climate change scenarios. To the extent that climate change increases the cost of implementing no-regret projects, the incremental cost of these projects should also be included in the costs of adaptation.

Related to the notion of adaptation costs is the concept of residual impact, which is defined as the change in welfare under the two scenarios. Since the impact of climate change is not likely to be beneficial for the majority of developing countries, it is reasonable to assume that welfare in the base case will be higher than in the case with climate change. The residual impact is the impact of climate change allowing for both autonomous and planned adaptation. To a large extent, this welfare loss is the result of the abandonment of projects P4, P5, and P6.

Accounting for the residual impact, another way to define adaptation costs is as the additional resources required to reestablish benefits from investments to what they would have been in the absence of climate change. Unlike the first definition of adaptation costs, which is likely to generate a minimum adaptation cost, this definition is likely to provide a maximum adaptation cost.

**Adaptation Costs: Formal Definitions**

More formally, the problem of project selection can be formulated and solved as an integer-programming problem. The objective is to select projects so that expected net benefits are maximized in each period, subject to a budget constraint. Moreover, the analysis will need to begin with the government's current investment budget; to ensure a coherent treatment of the government's overall fiscal balance through time, it will be important to consider the government's full investment budget.

The integer-programming problem then requires that in each period the planner select a subset of projects from a larger set $\boldsymbol{X_{it}}$ to maximize expected net benefits. Project $\boldsymbol{i}$ in each period is said require a flow of expenditure $\boldsymbol{C_{it}}$. The net benefits of investing in project $\boldsymbol{i}$ are similarly realized over the lifetime of the project and are denoted by $\boldsymbol{B_{it}}$. The present value of these future net benefits is given by $B_i = \sum_t \frac{B_{it}}{(1+r)^t}$ while the net present value of future costs is given by $C_i = \sum_t \frac{C_{it}}{(1+r)^t}$, where $r$ is the appropriate discount rate. Assuming a total budget of $\boldsymbol{C_t}$ for each time period over the model timeframe, the problem in each period may be stated as follows:

$$\max \quad E \sum_i B_i x_i$$

$$s.t. \sum_i C_i x_i \leq C_t \forall t$$

$$x_i \in \{0,1\} \forall i$$

where $\boldsymbol{x_i}$ is a binary variable indicating whether or not project $\boldsymbol{i}$ is selected in a given period. Note that since the integer-programming problem will be solved at the level of the economy, it may well be the case that the projects chosen in each period are drawn from one or two sectors rather than all sectors affected by climate change. This will nonetheless reflect an optimal allocation of national resources. Note also that net benefits will be a function of climate conditions and that the integer-programming problem will need to be solved for the ensemble of climate and non-climate scenarios to determine the set of robust projects.

Let $\boldsymbol{W}$ denote the maximized expected inter-temporal net benefits as a function of climate conditions and the budget constraint. If under the no-climate-change scenario, with climate conditions denoted by $\boldsymbol{T_0}$ and a budget constraint $\boldsymbol{C_0}$, the planner selects a portfolio of projects $\boldsymbol{A_0}$ that generate net benefits $\boldsymbol{W_0}$, the problem may be stated as follows

$$W_0 = W_0(T_0, A_0(C_0)).$$

Similarly, with the same existing budget constraint, $\boldsymbol{C_0}$, if $\boldsymbol{A_1}$ denotes the robust portfolio of projects under the projected climate conditions $\boldsymbol{T_1}$, and $\boldsymbol{W_1}$ denotes the maximized expected net benefits corresponding to these conditions, choices, and constraint:

$$W_1 = W_1(T_1, A_1(C_0)).$$

By the first definition, adaptation costs are defined as the cost of implementing projects chosen under $A_1$ that were not chosen under $A_0$ plus the incremental costs of the no-regret projects. With residual impacts defined as $W_0 - W_1$, the second definition of adaptation costs is the minimum cost of reducing the residual impact to "some" point, for example, 0 and thereby reestablishing the pre-climate-change level of benefits.

## IV. Five-Step Methodology

The study's proposed methodology consists of five steps:

- climate projections, assessment of exposure, climate sensitivity, and potential impacts;
- learning from the past: assessment of adaptive capacity and adaptation deficit;

- estimation of adaptation costs;
- macro-level assessment of adaptation to climate change; and
- generalization to all developing countries.

**Climate Projections, Assessment of Exposure, Climate Sensitivity, and Potential Impacts.** In order to assess what adaptation measures are needed in a country to moderate harm or exploit potential benefits due to climate change, and what such measures may cost, one needs to first understand and quantify the extent of exposure to climate risks, the sensitivity of the economy to climate variability, and the potential impacts, positive and negative, that climate variability imposes on the economy. For the purposes of this report, *exposure* is defined as the extent to which human populations and physical and natural assets are exposed to various climate risks; *sensitivity* is defined as the characteristics (of these populations and of the physical and natural assets) that determine the degree to which they are affected; and *potential impact* is the adverse or beneficial effect allowing for autonomous adaptation. Without such an understanding, it would not be possible to know who needs to adapt and to what.

The first step in the methodology thus consists of attempting to quantify key relationships among changes in climate parameters—such as average temperature, average precipitation, temperature and precipitation extremes, sea-level rise, and storm surges—and impacts on economic activities and livelihoods, measured through changes in agricultural productivity, changes in the productivity of forests and fisheries, and impacts on ecosystems functions, human health, infrastructure and coastal areas. The analysis begins with an understanding of which climate/weather and hydrological variables are likely to affect a given economic sector. Thereafter, projected trends in the relevant climate variables, obtained through statistical downscaling of results from GCMs, will be combined with sector-level impact assessment models to quantify potential impacts.

A sector focus for impact assessment, however, distracts from the fact that given groups within society may bear the brunt of a combination of sector-level impacts. The use of a livelihoods perspective makes it possible to assess some of these cross-sector effects and to better characterize the economic activities of vulnerable populations and the distributional impacts of climate change. Sector-level assessments will therefore be complemented by the livelihoods perspective, which requires the construction of a set of about six to ten stylized livelihood profiles of the most vulnerable groups representing a range of types of vulnerability to climate variability and change. Local vulnerabilities to a changing climate will in turn be established by combining climate and land use data with poverty maps and poverty assessments, including data on private, public, and natural assets.

**Learning from the Past: Assessment of Adaptive Capacity and Adaptation Deficit**. Having assessed "who needs to adapt and to what," the next step in the analysis is to learn from existing in-country experiences in dealing with past and current climate variability, including extreme weather events. This will entail learning from policies and projects that have and have not worked; learning from strategies employed by households and communities acting on their own without public policy interventions but within an existing public policy framework; and learning from state and federal policy measures to increase climate resilience of public investments, to enable autonomous adaptation, and provide safety nets to allow the vulnerable to cope with climate variability. In combination, such analyses allow for the assessment of a country's existing adaptive capacity, defined by IPCC as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences." Since it is important to understand not only what has worked but also what has not worked—why despite existing autonomous and planned adaptation measures some groups have been unable to cope with current climate variability—this step of the methodology will also assess the adaptation deficit.

This assessment of a country's adaptive capacity and adaptation deficit will then be used to develop a matrix of planned adaptation policies and projects by sector whose benefits would be assessed through project evaluation exercises or benefit transfer techniques, and whose costs would be assessed through compilations from project or sector budgets. Broadly speaking, adaptation measures can be classified as (a) providing public goods, (b) making public infrastructure more resilient, (c) enabling or promoting private adaptation, and (d) providing a safety net for the most vulnerable.

*Public Good Provision*. Adaptation measures that constitute public good provision include investments in (a) a wide variety of early warning systems (better weather forecasts to farmers; enhanced surveillance and monitoring programs for waterborne diseases; more targeted support for surveillance of fires, pests, and diseases in forests; etc.); (b) new technology development (more drought-resistant crops vaccines for dengue and other vector borne diseases, etc.); (c) public infrastructure (water storage, rainwater harvesting, sea-walls, etc.); and (d) helping populations in situations of extreme vulnerability and climate stress to relocate.

*Climate-Proofing Public Investments*. Adaptation measures under this category broadly require changes in the specifications of infrastructure investments to make them more climate resilient. For example, in the case of water availability, climate-proofing investments include:

- changing location or height of water intakes,
- installing canal linings,
- using closed conduits instead of open channels,
- integrating separate reservoirs into a single system,
- using artificial recharge to reduce evaporation,
- raising dam height,
- adding more turbines,
- increasing canal size, and
- removing sediment from reservoirs to increase storage capacity.

*Enabling Private Adaptation*. As previously discussed, a number of adaptation measures will be undertaken by private agents functioning within an overall policy framework. To the extent, then, that policies are developed to enable such autonomous adaptation, they too constitute adaptation measures. So, for example, policy initiatives to develop insurance markets can give farmers access to weather-indexed insurance, enabling them to cope with weather-related productivity shocks. Similarly, pricing water to reflect its scarcity will lead farmers to adopt cropping patterns that reflect local water availability; providing greater extension services will increase the capacity of farmers to deal with climate variability.

*Safety Net Provision*. Finally, adaptation measures implemented by both the state and private agents may be insufficient to allow households to cope with the impacts of large climate events. It is important, then, that goverments also build institutions to help with disaster relief and put in place programs that can provide additional incomes at such times. Employment creation schemes that guarantee a certain number of days of employment, typically at the minimum wage, and construction of emergency shelters in cyclone-prone regions are examples of such safety net adaptation measures.

It is important to note that an assessment of the costs and benefits of various adaptation measures is likely to be an ambitious endeavor as to date only limited sector-level estimates are available. As noted in a 2008 OECD study,[8] while there are a large number of estimates of adaptation costs and benefits for coastal zones, most studies in the agricultural sector have focused on assessing adaptation benefits, with few having attempted to assess the corresponding costs, and only a few isolated estimates of adaptation costs and benefits exist for all other sectors. Given this, it would be important to prioritize adaptation measures in each sector from the menu of measures identified above and to assess costs and benefits for this smaller set.

**Estimation of Adaptation Costs**. As noted above, estimation of adaption costs relies on the selection of the optimal set of projects with and without climate change. The menu of existing adaptive measures, compiled through learning from the past, may however not be sufficient to enable policymakers to select projects to maximize net benefits with climate change, as future climate patterns may be very different from current patterns. Thus it is important to complement understanding of current adaptation measures with identification of additional measures that may be needed to deal with projected climate variability. Participatory scenario development is one such approach. In particular, in-country workshops focused on participatory scenario development can be used to develop a robust understanding of feasible adaptation measures and pathways and their relevance for particularly vulnerable groups.

Adaptation costs would then be estimated first through identification of the set of projects that would have been implemented in the absence of climate change and the set that would have to be implemented to cope with the climate variability introduced by climate change holding constant the budget constraint (both sets identified through integer-programming). The costs of adaptation, also defined above, involve precisely the cost of implementing projects chosen under the with-climate-change scenario that were not chosen under the without-climate-change scenario, plus the incremental costs of no-regret projects. Alternatively, adaptation costs can be defined as the minimum additional resources required to reestablish benefits from investments to what they would have been in the absence of climate change.

**Macro-level Assessment of Adaptation to Climate Change.** The models and steps described thus far provide a detailed representation of climate sensitivity, potential impacts, and adaptation strategies at the sector and livelihood profile levels, holding input and output prices constant. Implementation of the set of adaptation measures identified above could well lead to changes in the demand for various inputs, such as labor, land, and capital, and thereby to changes in the

[8] Organisation for Economic Co-operation and Development (OECD), *Economic Aspects of Adaptation to Climate Change: Costs, Benefits, and Policy Instruments*, ed. by Shardul Agrawala and Samuel Franhauser (Paris: OECD, 2008).

prices of inputs and other goods in the economy. Such price changes would, in turn, affect adaptation costs. Consequently, such cross-sectoral, indirect effects also need to be accounted for to develop consistent estimates of adaptation costs at the national level.

The first, and critical, step in such a national assessment requires linking the "bottom up" approach, described above and used to select adaptation measures, with "top down" models used for economy-wide assessments such as computable general equilibrium (CGE) models. This, in turn, involves incorporating agent behavior and sector-level information obtained at the microeconomic level into a CGE model. The CGE model is then used to simulate three scenarios: the first corresponds to a no-climate-change situation, projects the path of economic development characterized by a set of input and output prices and estimates of consumer welfare; the second allows for climate change impacts without planned adaptation; and the third allows for both impacts and adaptation measures. Under the second and third scenarios, the magnitude of indirect effects can be assessed as well. Moreover, if the indirect effects are shown to be large and to add substantial additional costs to adaptation cost estimates then this suggests that there is a need to re-select the set of adaptation measures chosen in the previous step to reduce these indirect costs.

**Generalization to all Developing Countries.** The fifth and last step of the methodology consists of generalizing lessons from the six case study countries to all developing countries. This begins with the establishment of a common and consistent framework in each country, one of the key objectives of this proposed methodology. The framework involves constructing vulnerability areas categorizing areas of climate vulnerability based on indicators of (a) the nature of the climate event (for example, flood, drought), (b) the vulnerability of the affected population (for example, incomes, measures of capacity for collective action), and (c) GIS-based indicators of physical land characteristics (for example urban, rural, slope, soil type). Per-unit costs of adaptation based on country case studies can then be extrapolated to other developing countries with areas/populations with similar vulnerability characteristics.

In the case of the agricultural sector, adaptation options will be analyzed at the level of farming systems, as identified in the FAO/World Bank publication *Farming Systems and Poverty.*[9] Estimating adaptation costs by farming system unit facilitates the extrapolation of agricultural adaptation costs to all developing countries. Similarly, for other threats such as storm surge, urban flooding, and health impacts, homogeneous GIS-based extrapolation units can be identified, adaptation options analyzed, and average unit adaptation costs derived.

## V. Study Strengths and Limitations

The primary strength of the proposed methodology lies in its use of a consistent approach to extrapolating adaptation cost estimates from the sector to national and then to global levels. In doing so, the study hopes to fill two gaps in the literature on the economics of adaptation to climate change: (a) a lack of credible estimates on global adaptation costs, and (b) lack of guidance on optimal adaptation strategies at the sector and national level. Scalability of the proposed approach is made feasible by (a) the scope of coverage encompassing all key sectors in

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[9] John Dixon et al., *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World.*(Rome and Washington, DC: Food and Agricultural Organization and World Bank, 2001)..

six countries, (b) the multidisciplinary foundation, and (c) consistency in assumptions across the whole study.

The methodology builds on the information and assessments of adaptation to climate change already available at the sector and project levels, including agriculture, coastal, infrastructure, and health. The study proposes to redo previous estimates in these areas using a consistent set of assumptions and methodology so that the results can be aggregated to the country and global levels. Furthermore, new studies will be carried out for sectors and countries with no prior estimates, extending the domain of coverage among developing countries and thereby reducing the inherent uncertainties in extrapolation.

Another major strength of the study derives from its multidisciplinary approach. The proposed methodology attempts not only to link climate science with both microeconomic and macroeconomic models, but also to link each of these with social analytical methods.

Finally, the methodology proposes to use a consistent set of assumptions across all sectors and countries, including those on discounting, time horizons, treatment of climate predictions, treatment of inequality, and the target levels of adaptation explored.

The ambitiousness of the study poses its greatest challenges. In order to provide the minimum basis for generalization, six countries have been selected to serve as case studies (Bangladesh, Bolivia, Ethiopia, Ghana, Mozambique, and Vietnam). While providing these case studies is in itself an enormous undertaking, the study remains subject to criticism for not sampling a sufficiently wide range of countries to permit generalizing their adaptation experiences to all developing countries. Additional challenges arise from the study's complexity as a result of its data-intensive nature, high computational requirements, uncertainty regarding key parameters such as climate predictions, the challenge of linking micro and macro models, and the need for consistency across all of these domains. These requirements pose a particular challenge since the amount and quality of data vary greatly from country to country.

**Uncertainty.** All results in any study of climate change, including this one, are driven by the climate change forecasts that originate in the GCM models. There are inherent uncertainties in the results produced by these models both from the time horizons over which forecasts are made and from the modeling approaches used in the various GCMs and optimization models. At a local scale, the GCMs disagree not only in the magnitude of change that is to be expected but even on the direction for the same climate change scenarios. Other uncertainties originate from the imprecision of models (science, economics, and social impact), including basic forecasts of economic development in a 50-year time horizon. While some of these uncertainties have been appropriately dealt with as part of the analysis leading to optimal adaptation strategies under specific scenarios, uncertainties remain.

**Selection Bias in Adaptation Initiatives.** The proposed approach estimates adaptation costs at the sector level largely by reviewing the cost of specific adaptation initiatives that have been taken in response to past climate variability and of proposed projects intended to confront future changes. Such initiatives can be limited, as in the case of soft policy initiatives, which are difficult to cost out compared to hard initiatives. Even when there is a large sample of initiatives, the limited local context and circumstances may make them non-representative or sub-optimal for extrapolating to the remainder of the sector. This is especially likely to be true for the social analysis conducted based on local consultations but also may affect other, more heterogeneous sectors.

**Treatment of Externalities.** Adaptation measures may generate significant non-pecuniary externalities. To the extent that these externalities can be internalized based on widely agreed methods, the study will do so. Where externalities are uncertain, or valuation difficult and controversial, the study will discuss the existence of the externality qualitatively but will not incorporate the externality in the quantitative analysis. The justification for this is to minimize the potential for perceived subjectivity to discredit the quantitative results.

**Financial versus Economic Analysis.** Ideally, the analysis of optimality of adaptation packages would be done in economic rather than financial values. The calculation of the cost of financing adaptation starts with the units that governments and donors actually face in the marketplace—financial costs. Given the scale and time available, the study will explore the possibility of optimizing economic values but calculate the costs in financial values, depending fundamentally on the availability of experienced in-country project analysts.