THE ECONOMICS OF ADAPTATION TO CLIMATE CHANGE

FINAL METHODOLOGY REPORT[1]

February 2009

[1] This Final Methodology Report reflects important updates which were made to a previous version which was available for consultation in the EACC Study Website: (*http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/EXTCC/0,,contentMDK:21581098~pagePK:210058~piPK:210062~theSitePK:407864,00.html*). It maintains the previous bottom-up approach to estimate the global costs of adaption based on scaling-up estimates obtained in six country-case studies, and now also includes a global estimate based on global datasets, extensively ground-truthed in country datasets and information.

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This study is being conducted in partnership between the World Bank (leading its technical aspects), the governments of the United Kingdom, The Netherlands, and Switzerland (funding the study), and the participating case study countries. The findings, interpretations, and conclusions expressed in this paper do not necessarily reflect the views of the Executive Directors of The World Bank or the governments they represent.

I. Background and Study Objectives

Current estimates of the cost of climate change in developing countries and of the needed adaptation measures are in very short supply, and the ones available are rather crude and/or simplistic. This is largely because the economics of adaptation to climate change is a new research area and no agreed methodology to assess overall costs has yet emerged. Moreover, computations are made more complicated by data limitation in vulnerable countries. 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 to both enable developing countries to implement their national strategies and plans and to inform discussions concerning possible international assistance. In order, then, to develop estimates of the cost of adaptation at the national and global level, a partnership has been formed between the World Bank and the governments of the Netherlands, the UK, and Switzerland, in which the World Bank has been tasked with leading the technical aspects of the study while the Netherlands, UK, and Switzerland have agreed to fund the analysis.

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

The second objective is to develop a "global" estimate of adaptation costs to inform the international community's efforts, including UNFCCC and the Bali Action Plan, to provide access to adequate, predictable, and sustainable support, and to provide new and additional resources to help the most vulnerable developing countries meet adaptation costs. In particular, a consistent global estimate of the costs of adaptation to climate change in developing countries could potentially greatly support the Copenhagen process.

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 socio-cultural 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. In principle, the study team intended to link these objectives by doing the case study countries as pilots, linking the microeconomic analyses with national, macroeconomic ones by using computable general equilibrium models, and then estimating the "overall costs" of adaptation by developing methods to extrapolate adaptation costs from the limited number of case study countries to all developing countries. The idea was to apply unit least costs of adaptation measures obtained from the country case studies to similar adaptation conditions in other developing countries as defined by GIS data.

The six country case studies were selected based on a variety of criteria indicated in the Study's Concept Note, 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 but excluding its last two sections, has been developed and the scope of the analysis to be used in Phase 2 defined. During Phase 2, research and analysis at both the global (see below) and the country level will be carried out, drawing on both existing and new research in the six case study countries.

Apart from the delicate step of generalizing the results from six country case studies to all developing countries, the "bottom-up" approach clearly requires a high degree of engagement by counterpart governments. This is not only politically necessary, but is also a crucial first step towards developing local capacity on climate change issues and strengthening links between governments, donors, and the Bank in this area.

As the team presented and discussed the proposed methodology with local governments, however, it became clear that they were not all at the same level of interest, knowledge, capacity, and information. It would be enormously difficult to impose a somewhat consistent approach across all country case studies, using equal methodologies and assumptions, and proceed at the same pace in all countries, in order to prepare a baseline on which to escalate the estimates to the global level. The time required to achieve this was incompatible with the timing of the other objective of the study, which is to inform the Copenhagen negotiations.

In order to ensure the timely availability of a global estimate, the study team decided to proceed on a parallel track: one which is based on the country case studies, ground-truth on local databases and on work by national experts, as well as on discussions with local stakeholders – the *bottom-up* approach – and another which aims to produce a global estimate based on global datasets, but with a high degree of ground-truthing and country data – the *top-down* approach. The new challenge is, of course, not to generalize the estimates from six countries to all developing countries, but to link the bottom-up approach based on the six country case-studies, and the top-down approach, which is based on global analyses and global datasets.

The current Methodology Report is an update of a previous version which has been posted on the study's web-page: (*http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/EXTCC/0,,contentMDK:21581098~pagePK:210058~piPK:210062~theSitePK:407864,00.html*). It maintains the previous bottom-up approach to estimate the global costs of adaption based on scaling-up estimates obtained in six country-case studies, and now also includes a global estimate based on global datasets, extensively ground-truth in country datasets and information. It also contains a new section which discusses the links between the two approaches, and the overall pros and cons of each.

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."

The Report is divided in five sections in addition to this introduction. Section II discusses a few peculiarities of the sole concept of adaptation, which make the problem theoretically and practically quite unique. Section III brings the previous theoretical discussion to a more operational level, including clearer definition of various commonly used terms. Section IV presents the four steps of the bottom-up methodology based on the country case studies. Sections V and VI are the new sections. Section V describes the top-down methodology – how to estimate the global costs of adaptation based on global datasets, including major simplifying assumptions, data available, and sector methodologies; Section VI discusses the links between the bottom-up and top-down approaches.

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),[2] 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.

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 –

[2] 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.

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.[3]

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 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

[3] 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.

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[4] 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.[5] 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[6] 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).[7] 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 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

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

[5] 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.

[6] 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.

[7] 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.

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.[8]

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

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

famous Ramsey Rule ($r = \delta + \eta.g$, where r denotes the discount rate, δ the rate of pure time preference, η 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.

III. Operational Definition of Adaptation Costs

The concept of adaptation costs appears intuitive, being the costs incurred by societies to adapt to changes in climate 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

The problem of project selection can be formulated and solved more formally as an integer-programming problem. The objective is to select projects so that their expected net benefits are maximized in each period, subject to a budget constraint. The analysis needs 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 X_{it} to maximize expected net benefits. Project i in each period requires a flow of expenditure C_{it}. The net benefits of investing in project i are similarly realized over the lifetime of the project and are denoted by 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 C_t for each time period over the model timeframe, the problem in each period may be stated as follows:

$$\max E\sum_i B_i x_i$$

$$s.t.\sum_i C_{it} x_i \leq C_t \forall t$$

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

where x_i is a binary variable indicating whether or not project 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 (those who perform "well" under most scenarios, rather than being optimal under a certain scenario and a poor performer under others).

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

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

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

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

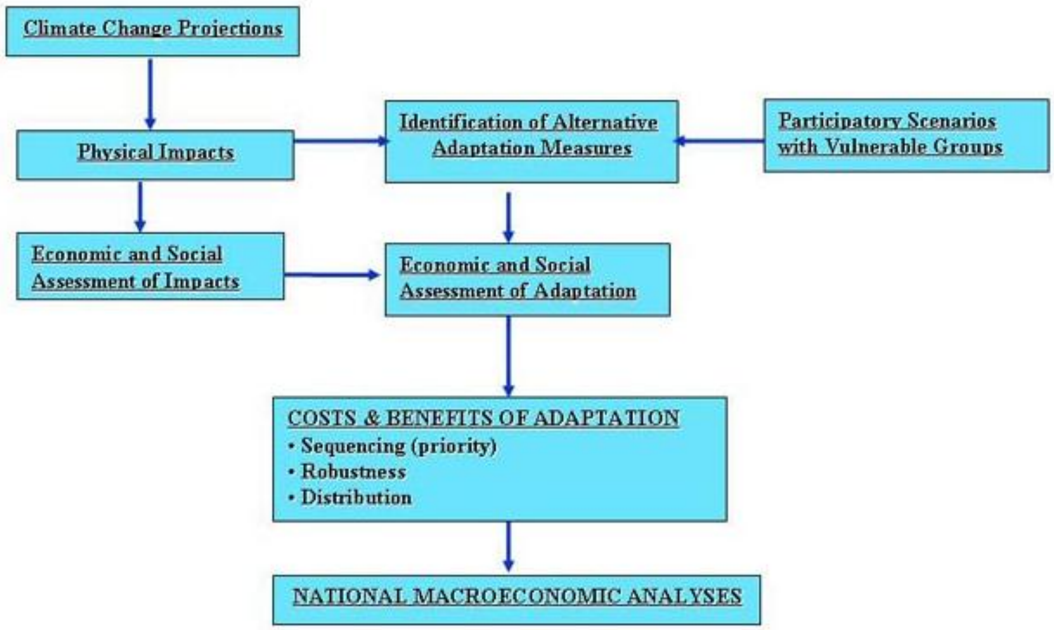
By the first definition, adaptation costs are defined as the cost of implementing projects chosen under A_1 that were not chosen under A_0 plus the incremental costs of the no-regret projects. With residual impacts defined as $W_0 - W_1$, the second definition of adaptation costs is the minimum cost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

IV. A Four-Step Methodology: the Bottom-Up Approach

The study's bottom-up proposed methodology consists of four steps – see Figure 1:

- 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; and
- Macro-level assessment of adaptation to climate change.

FIGURE 1: Schematic View of Bottom-Up Approach



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 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 governments 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,[9] 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

[9] 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).

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 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 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.

V. The Top-Down Approach: Global Estimates of Adaptation Costs

V.1 Existing Estimates

The first estimate of costs of adaptation to climate change for developing countries was produced by the World Bank in 2006 – Table 1. In this report, adaptation costs were defined as the cost of climate-proofing three categories of investment flows – ODA and Concessional Finance, Foreign Direct Investment, and Gross Domestic Investment. The estimate first defined the proportion of total investments in each category that was likely to be climate sensitive, and then estimated the percentage increases in costs to climate-proof these investments. This approach produced adaptation cost estimates in the range of $9-41 Billion per year.

TABLE 1: Estimates of Adaptation Costs by Investment Categories

Item	Yearly Amount	Estimated climate sensitive portion	Estimated costs of adaptation	Yearly Total (2000)
Concessional and ODA Finance	$ 100B	40%	10-20%	$4-8B
Foreign Direct Investment	$160B	10%	10-20%	$2-3B
Gross Domestic Investment	$1500B	2-10%	10-20%	$3-30B
Total				$9-41B

Source: World Bank (2006)

Not surprisingly, this estimate of global adaptation costs is sensitive to the values used to define the proportion of climate sensitive investments as well as to the increases in costs for climate-proofing investments. And so, for example, using the same methodology but different parameter values, the Stern Report (2006) estimated that costs of adaptation were likely to lie between $4-37 Billion per year, somewhat lower than the World Bank estimate, while the Human Development Report (2007) estimated that costs would lie between $5-67 Billion per year by 2015,[10] somewhat higher than the World Bank estimate. None of these studies, however, provides a strong analytical basis for its choice of parameter values. Moreover, none of them accounts for (i) costs of climate-proofing *existing* stocks of capital or (ii) costs of financing new investments, beyond those planned for development-as-usual, that will be needed specifically to adapt to climate change.

In contrast to this more "top-down" approach, Oxfam International (Oxfam 2007) took a "bottom-up" approach to estimate adaptation costs through an assessment of National Action Plans for Adaptation (NAPAs) and of costs of NGO-initiated adaptation projects. According to this report, global adaptation costs are likely be at least $50 Billion per year assuming average warming of 2^{o}C: $7.5 Billion per year to support NGO-initiated adaptation efforts,[11] $8-33 Billion per year to meet the costs of most urgent adaptation measures being proposed under the

[10] In addition to costs of climate proofing investments, the Human Development Report (2007) estimated that $40 Billion per year by 2015 would be required to "strengthen social protection programs and scale up aid in other key areas," and another $2 Billion per year by 2015 to strengthen disaster response systems. These additional costs put the range of overall adaptation costs between $47-109 Billion per year by 2015.

[11] Using cost-benefit estimates from a small sample of existing NGO-initiated adaptation projects, the report first estimated that "the average cost for NGOs to provide community-based support for adaptation – over a diverse range of risks, and diverse countries – is currently around $20 per person" (pp. 20, Oxfam 2007). Assuming that 40% of the 2.8 billion people currently living on less than $2 a day would require support from NGO-initiated adaptation projects, then provided an estimate of $7.5 Billion per year.

NAPAs,[12] and $5-15 Billion per year to address unknown and unexpected impacts. Though richer in terms of range of potential adaptation measures and not only climate-proofing investment flows, this methodology suffers from trying to generalize to all developing countries using a small, and likely un-representative, sample of projects and countries.

The final set of estimates of costs of adaptation to climate change for developing countries were produced by the UNFCCC in 2007 – Table 2. Whereas previous efforts only considered the costs of planned adaptation, this report considered the costs of both planned and private adaptation measures. Also, whereas previous estimates considered costs across all sectors, this report estimated the costs of adaptation to climate change by major sectors – Agriculture, Forestry, and Fisheries (AFF), Water Supply, Human Health, Coastal Zones, and Infrastructure. Costs of both private and planned adaptation totaled across the five sectors were estimated to lie between $28-69 Billion per year by 2030.

TABLE 2: Estimates of Adaptation Costs by Sectors

Sector	**Costs for Developing Countries ($ Billion)**	**Financing**
Agriculture, Forestry, Fisheries	7	Mostly Private
Water Supply	9	Mostly Public
Human Health	5	Public and Private
Coastal Zones	5	Mostly Public
Infrastructure	2-41	Mostly Public
Total	28-69	

Source: UNFCCC (2007)

V.2 EACC Approach

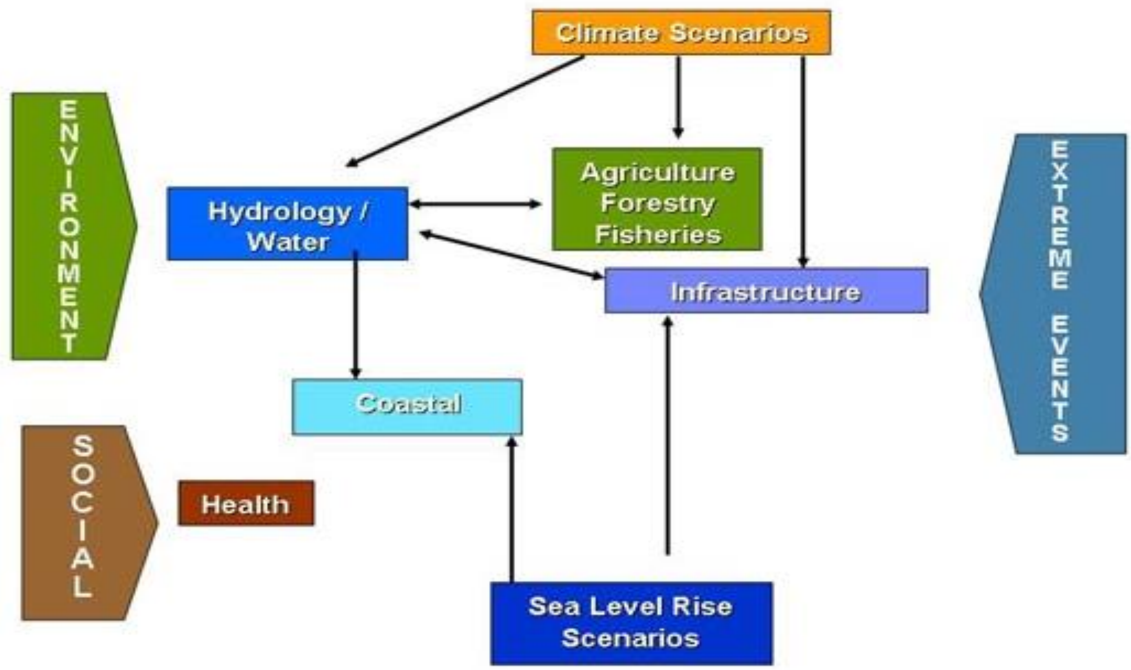
Like UNFCCC (2007), our study will estimate the costs of adaptation to climate change for developing countries by sector, focusing only on the costs of planned adaptation measures. It will also build on the UNFCCC report and the other studies in a number of ways.

First, although our study will consider more or less the same set of sectors as UNFCCC (2007) (see Figure 2), it will analyze these at a greater level of detail. For example, and as described below, our study will analyze different types of infrastructure services – transport, energy, water and sanitation, communications, and urban and social infrastructure – and estimate the cost of adaptation to climate change for each of these categories. The UNFCCC study, on the other hand, uses the same methodology as World Bank (2006) for the infrastructure sector, estimating infrastructure investment costs for the whole sector as the cost of adapting the climate-sensitive

[12] Cost of adaptation projects proposed for the most urgent measures under NAPAs for thirteen least-developed countries most vulnerable to climate change amounted to $330 Million per year. Extrapolating these costs to all developing countries using either size of population, size of the economy, or area of land used for human activity then gave an estimate of $8-33 Billion per year.

portion of new-investment flows. Neither risks of climate change, nor costs of climate-proofing are differentiated by type of infrastructure.

FIGURE 2: Sectoral Coverage of Global Track



Second, in our study, the impact of climate change and the costs of adaptation will be analyzed for climate projections derived from a range of emission scenarios (specifically A1B, A2, and B1), and a range of global circulation models per emission scenario (based on best-fit per country). A range of climate projections will, in turn, allow the study to identify robust adaptation measures, thereby accounting for the inherent uncertainty in climate change analysis. UNFCCC (2007) does not use a consistent set of climate projections across sectors to derive its estimates, let alone a range, and prior studies make no link between climate projections and adaptation costs[13].

Third, unlike previous estimates, our study will explicitly consider the relationship between development and adaptation when estimating adaptation costs over the period 2010 and 2050. Most existing studies hold developing countries at their current level of development when estimating adaptation costs for both the near- and medium-term. Over the medium-term these countries will, however, become more developed and this, in turn, will change the impact of climate change on their economies and the type and extent of adaptation needed. Our study will account for the impact of development on estimates of adaptation costs by projecting

[13] Adam Schlosser (MIT) will be working with the team to provide consistent climate projections across sectors and Ken Strzepek (University of Colorado) will build on work being done for the Water Anchor at the World Bank to provide global estimates of run-off and changes in flood frequency.

development as usual (that is, development in the absence of climate-change) out to 2050 and estimating adaptation costs against this baseline[14].

Fourth, our study will use an economically efficient definition of adaptation costs and will do so consistently across sectors. Specifically, for the purposes of the global assessment and in each sector, adaptation costs will be defined as the minimum cost of projects and programs required to return each sector to its pre-climate change standard. In the water sector the standard may be given by the storage yield curve, in agriculture by levels of nutrition, and in the infrastructure sector by the level of services. Care will be taken to ensure that costs are not counted twice, for example, irrigation costs in both water and agriculture, nutritional costs in both health and agriculture. As described in Section III, an alternative definition of adaptation costs would be the cost of restoring pre-climate change standards to levels where benefits exceed costs, plus the residual damage. This definition, however, is difficult to operationalize in the context of global sectoral assessments as models for such assessments do not optimize across space or time. To the extent possible, though, we will try to implement the alternative definition of adaptation costs as well. This will be done, for example, for the coastal sector, and the team is exploring the possibility of doing so in the other sectors as well.

Finally, instead of using uniform cost rules to estimate the costs of projects and programs for different countries, our study will draw on the wealth of cost estimates available from World Bank project reports (both Project Appraisal Documents and Implementation and Completion Reports) to develop cost estimates for adaptation measures that are differentiated by region, if not by country. Depending on the progress of the bottom-up approaches being done in partnership with the six developing country case studies, these estimates will be further ground-truth on local current data, studies and information obtained directly from interviews directly funded by the study. The EACC significant effort to obtain "real" country information and costs will not only strengthen the reliability of the estimates and the links between the top-down and bottom-up approaches, but will also improve knowledge relative to the existing studies.

V.3 Sector-Specific Methodology

A. Infrastructure

For the purpose of this study infrastructure has been given a rather broad definition, including the usual types of infrastructure services – roads, rail, and ports; energy; water & sanitation; and communications – as well as urban and social infrastructure, such as urban drainage, urban housing, health and educational facilities (both rural and urban), and general public buildings. The methodology starts from the assumption that climate change will require two types of adaptation with respect to infrastructure assets:

(i) The unit costs of providing infrastructure services will change, most probably becoming more expensive. This will be reflected in both higher capital and operating costs.

[14] Gordon Hughes (University of Edinburgh) will be working with the team to develop these baselines and to ensure that they are consistent across sectors.

(ii) The quantities of infrastructure assets required (holding income constant) will change as a consequence of different climatic conditions, and this has two dimensions: climate change may change the level or composition of demand for energy, transport and water at given levels of income; and second climate change will force countries to invest in specific additional assets in order to maintain standards of protection for non-infrastructure activities.

Basic framework. The analysis is based upon a baseline projection of growth in income and infrastructure stocks over the period 2010-50 assuming sensible policies. The baseline projection will be constructed using panel data equations linking observed levels of infrastructure assets to GDP, economic structure, population and physical characteristics including climate variables. Future growth in income & population – taken from external sources – will be combined with long run trends in economic structure to generate the projected demand for infrastructure assets up to 2050 holding physical and climate variables constant.

The next step is to estimate the change in the unit costs of acquiring and operating infrastructure assets under alternative climate scenarios. It should not be difficult to predict how alternative projections of climate change will influence the severity of weather events and in turn how the assets must be designed to cope with in order to hold constant their design life and performance. Using engineering and other information we will estimate the percentage change in the average unit cost of building infrastructure assets of different types. A similar approach will be followed with respect to maintenance and other operating costs. The cost of adapting to climate change may be calculated by looking at the change in the annualized cost of infrastructure at each date.

The change in the demand for infrastructure assets due to the change in climate may be estimated by comparing the baseline scenario with the projected demand for infrastructure generated using the baseline economic assumptions combined with alternative climate variables.

Finally, the specific additional investments will be generated by analysis of the impact of changes in sea level and storm surges on coastal regions. A broad brush comparison of the costs and benefits of building coastal levees or other forms of protection will be developed (based on Nicholls 2008). A similar approach will be used for major rivers with respect to the assessment of flood defenses.

Coverage and strategy. A database of country level information is being compiled for the period 1960-2005, though it will contain many missing variables. In Phase 1 of the study (up to mid-April) the goal will be to generate initial estimates of the cost of adaptation for 3 countries – provisionally Brazil, South Africa and China. Since these are large countries with substantial within-country differences in the impact of climate change on local climates, the intention is to undertake the analysis at the level of states/provinces and assume some pattern of convergence in within-country income differences to project the composite indicators of infrastructure demand.

In Phase 2 (to end-May) the analysis will extend to cover about 30 countries with populations greater than 30 million accounting for about 85% of the population of the developing world. Finally, in Phase 3 we will include the remaining 90 developing countries with populations in the range 0.5 million to 30 million. The data is much more incomplete for these countries and it is likely that a considerable amount of interpolation or scaling up of figures for other countries will be required.

Limitations. This exercise can only yield broad-brush estimates of the cost of adapting infrastructure assets to climate change. The absolute numbers will be of limited use, but the results expressed as a proportion of the total cost of providing infrastructure services should provide an indication of the relative magnitude of the problems faced by different countries.
It is probable that our approach will yield estimates of the cost of adaptation that are significantly too high in the longer term. This is both because technical change will tend to make investments in infrastructure more resilient to climate impacts, as well as because the approach assumes that the design lives and performance of all infrastructure assets will be maintained, and this may not be economically sensible.

B. Agriculture

The methodology will be based on simulations of the IMPACT model (Rosegrant *et al*, 2001) – see Box below. A unit-cost approach is used to calculate the incremental public investment requirements that are implied by simulated changes in key drivers affecting agricultural growth under a baseline scenario with no climate change, compared to scenarios with moderate climate change and a more extreme climate change scenario.

The IMPACT Model

The model uses a system of equations to approximate the underlying production and demand relationships of world agriculture. It uses country-level supply and demand elasticity estimates. The world's food production is disaggregated into 281 food production units (FPUs) defined to be countries or watersheds within large countries. The model includes 32 major commodities, and models the behavior of a competitive world agricultural market for crops and livestock, and is specified as a set of country or regional sub-models, within each of which supply, demand and prices for agricultural commodities are determined. The country and regional agricultural sub-models are linked through trade so that the interactions among country-level production, consumption and commodity prices are captured through net trade flows in global agricultural markets. Demand is a function of prices, income and population growth. Crop yield is a function of crop and input prices, water availability and productivity growth, which is a function of investment in agricultural research and development, rural infrastructure and irrigation.

Climate change effects, including CO_2 fertilization will be added to the IMPACT model with the use of reduced form productivity functions derived from DSSAT model runs and a neural net estimation process. A cropping calendar derived from the SRES scenarios to alter the hydrology inputs into the IMPACT model will be used.

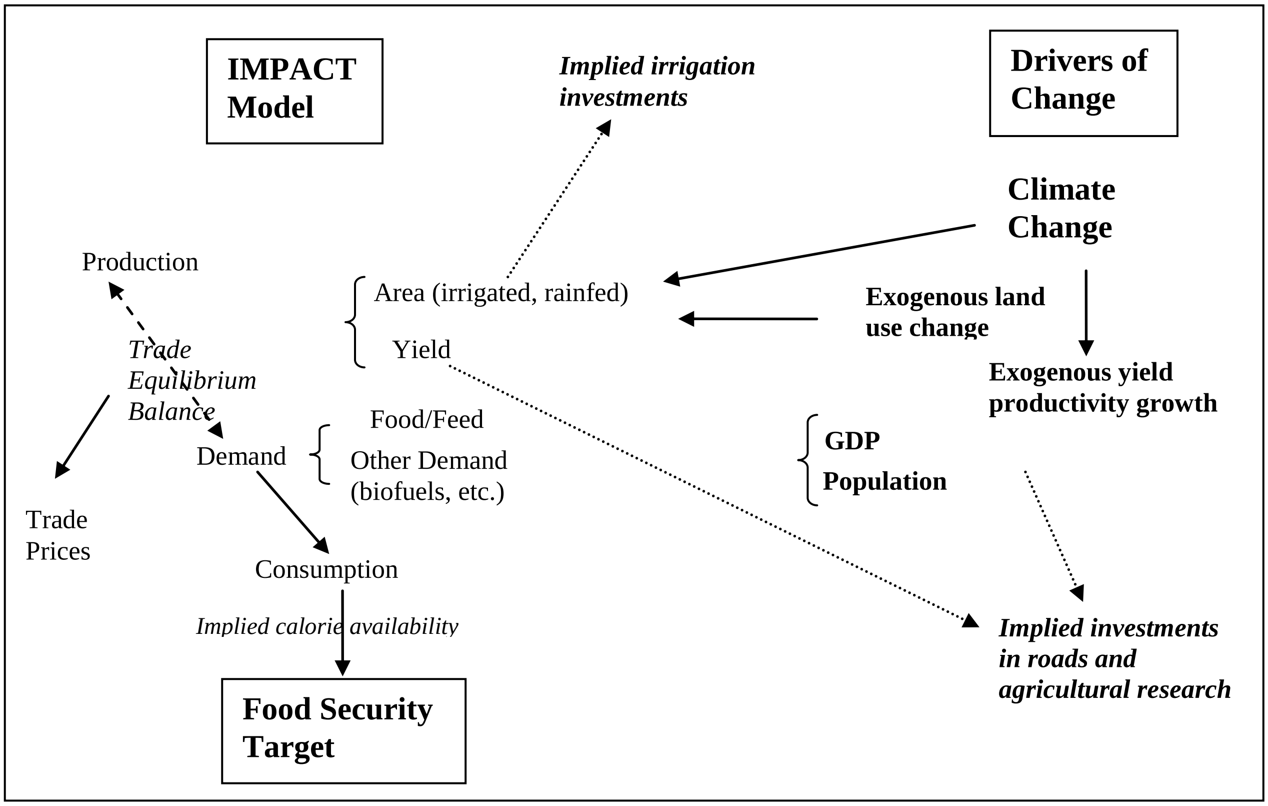
Within IMPACT, changes in area are modeled with response functions that react to changes in crop prices, through own- or cross-commodity elasticities. Other drivers of land use change (degradation, encroachment of urban area, desertification, expansion into forested area) are not modeled explicitly within IMPACT, and are handled through exogenous rates of change that are scenario-specific, pre-specified parameters within the model. From the simulated growth in total crop area, the model disaggregates the component that represents area under irrigation, and this is then used in investment calculations.

The simulations that have been done with IMPACT model are carried out within a partial-equilibrium framework focused mainly on the market-based interactions between supply and demand of key agricultural commodities. There is no explicit modeling of the interactions with non-agricultural sectors of the economy that also generate income, employment and contribute to the overall economic output. Therefore, the model takes total projections of overall economy-wide income as exogenously given. Population growth is also an important driver of agricultural markets and is exogenous to the model.

The baseline population growth is derived from the medium-variant projections of the UN population statistics division (UN, 2004). For our with-climate-change scenario we will likely use GDP and population growth rate assumptions consistent with the high-climate change scenario. The model then derives the average per-capita income that is used to determine year-to-year consumption changes across different food commodities, that determine how diet composition evolves over time in different regions in addition to those changes in consumption that are driven by changes in the actual market prices of those commodities.

The basic linkages between the various socio-economic and biophysical drivers that determine the trajectory of IMPACT simulations are shown in Figure 3. Yield growth is a major component of crop production growth in many regions, and is linked to improvements in agricultural performance that can be influenced either directly through irrigation, agricultural research investments or investments in rural roads. Figure 3 also shows other complementary investment-driven public sector services that are important for the welfare outcomes that are simulated in IMPACT.

FIGURE 3: IMPACT Model, Drivers of Change, and Welfare Outcomes



The variables that climate change affects most directly are yield productivity growth for all crops and productivity in irrigated systems. Climate change will alter growing season starting months, water availability for both irrigated and rainfed production systems and temperature stress; all of which impact crop productivity. Productivity in irrigated systems depends on sufficient water availability from precipitation and storage.

To assess adjustment costs, we will estimate the investments in irrigation, agricultural research and rural roads that return food availability and prices to the baseline levels. Investment needs can be calculated based on the methodology described in Rosegrant et al. (2001). When reliable, disaggregated country-level data are not available, we will employ global averages as a second-best approximation of real costs. The results should thus be viewed as a guide to the level of investment effort required to generate outcomes on a regional and large-country basis, and the figures are intended as ballpark estimates of total costs and a basis for regional comparisons. Additional analysis would be required to synthesize and prioritize investment decisions in individual countries.

Expenditures for public agricultural research are based on expenditure trends and projections and their relative contribution to crop yields and take into account public expenditures from both national and international sources. Total irrigation investments are calculated by taking the projected irrigated area and multiplying the area with incremental per-hectare irrigation costs. The investments in rural roads are calculated by taking the additional expenditure of road systems necessary to support the projected increases in yield and multiplying them by unit costs for road construction. The proportion of yield growth that is attributable to road expansion and the effect of road investments on crop productivity are based on estimates from the literature.

C. Coastal Zones

To provide adaptation response costs to sea-level rise and storm surges which avoid the vast bulk of coastal damages to infrastructure, and restore people, assets, and activities to the level of protection without climate change, the Dynamic Interactive Vulnerability Assessment (DIVA) tool will be used (DINAS-Coast Consortium, 2006). This tool includes flood and erosion models which estimate both damage and costs in response to planned adaptation in the form of dike construction and beach/shore nourishment. Infrastructure is not explicitly defined in the model's database, but is estimated via population distribution and GDP. The flooding model assesses temporary inundation of land areas and associated values, while erosion deals with damage to tourism and touristic infrastructure. The costs of these measures are derived from coastal engineering experience, including the Global Vulnerability Analysis (Hoozemans *et al.* 1993) for the capital costs of dike construction and upgrade and the Environmental Protection Agency (EPA)'s International Study (with updates) for beach nourishment. Optimum dike and beach protection is estimated on a cost/benefit basis and risk aversion. The relationship between nourishment and reduction of flood risk is implicit in the model. Residual damage is also calculated in DIVA, but as this is small it will not be considered.

In addition to DIVA costs, we will examine the costs of port upgrade due to sea-level rise and storm surges. This will use the original IPCC CZMS (1990) estimates as a starting point and look at new studies such as the recent OECD assessment of port cities (Nicholls et al., 2007).

D. Other Sectors and Issues

The EACC team has been focusing on the three above sectors/themes in terms of the global track approach. This is because they are assumed to account for the largest share of the global costs of adaptation to climate change in terms of the economic sectors. The idea is that once the work is fully launched by the various groups and individual consultants, the EACC team will finalize methodologies and proposals for the other sectors. It is yet unclear whether or not all the sectors and issues below will be included in the analyses. This will basically depend on the existence and immediate availability of data, and the team's own judgment about the possibility of implementing the proposed methodologies in the given timeframe, and the possibility of linking the specific sector analysis with those being done in the other sectors. Though a little general and at an uneven level of specification, the team decided to include a short description of the preliminary ideas regarding methodologies and approaches in other sectors.[15]

[15] The summary descriptions do not include the forestry sector, which will be potentially included in the analyses, as well as social issues. Unlike the bottom-up, national analyses, where the social methodology was discussed with the sectors and "mainstreamed" in the economic analyses, in the global track it yet remains unclear whether or not, and how, social issues will be explicitly addressed and inferred, other than through the results of the various sectoral and global economic analyses. Of particular interest are migration and distributional effects.

In the **water resources** sector we will develop costs of adaptation to restore storage yield curves for major water reservoirs in developing countries as well as costs of protection against changes in flood frequencies in non-urban areas. Using the results of the hydrologic modeling using the CLIRUN II model, we will provide estimate of costs of restoring national basin yield through investments in reservoir storage using the technique developed by Strzepek (2008). The key element is to develop a local production function for water yield that is a function of river flow, topography and reservoir size.

In the **health sector**, the costs of adaption to climate change will consist of the costs of treating additional people who become ill as a direct or an indirect consequence from climate change, and the costs of preventing these cases. The costs of treatment for the additional cases of malnutrition, malaria, and diarrheal diseases will be estimated in three steps: (a) compilation of the current level of incidence of these diseases by country from WHO databases; (b) determination of the relative risk of these diseases for 2030 and 2050 due to climate change, measured against the development baseline; and (c) determination of the per unit cost of treatment of these disease endpoints based on information available in the Disease Control Priority Database and World Bank projects. The relative risk for each of these endpoints will be based on the dose-response functions defined in a WHO 2007 study. The estimates for diarrheal disease and malaria will be based on the common climate scenarios being used in the study. The relative risk of malnutrition, on the other hand, will be based on the results from the agricultural sector, described above. Similarly, the costs of disease prevention, accounting for increases in geographic ranges and extensions into new areas, will be estimated in two steps: (a) determination of the need for such expansion in services; and (b) use of results from the infrastructure sector to determine unit cost of expansion of such service.

Assessment of adaptation costs in the **fisheries sector** will begin with an estimation of the physical impacts of climate change on this sector. For marine fisheries, potential fish catch and distribution by species will be estimated by reviewing the latest macro-ecological model predictions of climate change and marine ecosystems. These models are based on global datasets of biology and fisheries (e.g. Fishbase) as well as predicted distribution ranges and spatially explicit catch data of over 1300 commercially exploited fish (e.g. Searoundus). For freshwater fisheries, water availability will be coupled with biological models of freshwater fish species to determine the potential catch at the river basin level. To the extent possible, the effects of changes in flood frequency, storm surge and sea level rise in coastal areas will also be incorporated into the analysis. Predicted biophysical and ecological impacts will be overlaid with other vulnerability indicators to determine the potential economic losses at the country level. Finally, a range of adaptation strategies will be analyzed to determine the cost of restoring the productivity of the fisheries sector. Adaptation strategies include investments in flexible technologies such as multipurpose boats (as opposed to specialized vessels) and flexible processing chains, and increasing opportunity for alternative livelihoods during lean periods.

Despite controversies surrounding the issue of **valuation of ecosystem services**, the study will also attempt to provide estimates of cost of adaptation to climate change for ecosystem services. Building on studies such as Vergara et al, 2008[16] that estimates the total cost of losing coral reefs ecosystem services by 2080 under the A1B scenario, the study will begin with an assessment of

[16] The potential consequences of climate-induced coral loss on the Caribbean by 2050-2080. World Bank, 2009.

climate change impacts on major global ecosystems. At present, the team is unclear about the level of analyses and thus of the ideal database on which to base the estimates. Assuming this information is available in a consistent manner at the global level, it will then be possible to estimate the overall cost and benefit of restoring and/or maintaining particular ecosystem services as adaptation measures to future climate risk and change. This will be done by estimating the broad associated cost of the restoration of degraded ecosystems to a baseline (defined as current climate variability) and maintenance cost of these services under different climate change scenarios.

V.4 Cross-Sectoral Approaches

A. Global CGE

As was the case for the country case studies, a sectoral approach to estimating adaptation costs at the global level does not allow for indirect economic effects of these investments which may, in turn, affect the overall costs of adaptation. Computable general equilibrium (CGE) models are well-suited for this purpose as they link markets into a single system and capture feedback and flow-through effects induced by policy changes. As the world is divided into regions, CGE models combine inter-sectoral linkages within regions together with bilateral linkages among regions. We will begin by calibrating global model with country-and sector-specific damage functions to available empirical evidence (e.g. Cline, 2007) to provide a baseline. Different climate scenarios will then be applied to the baseline to generate climate change impacts and thereby to estimate the costs of adaptation. As future emission pathways are treated exogenously in our study, we will consider two approaches for estimating the cost of adaptation for all developing countries. The first approach will be the simulation of additional investment needed to restore developing countries' hypothetical welfare without climate change and the second scenario will be the simulation of additional investment needed to equate marginal cost of adaptation to marginal avoided damages. This work will be done in conjunction with the Bank's Development Economics Department (DEC), which is already doing research on the economics of climate change at a global level using a CGE model, although currently not (yet) incorporating adaptation issues.

B. Extreme Weather Events

Finally, analysis of historical data on fatalities resulting from extreme weather events will be used to provide overall estimates of damages due to climate change that can be used as an upper bound for cross-sector country level adaptation costs.

Public and private agents face a resource allocation decision when confronting climate risks. Losses of expected life tend to dominate benefit-cost calculations for addressing many environmental risks (e.g. local air pollution control). This is likely true for climate risks as well. Three basic factors determine the risk decision: the expected risk (loss of life), the cost function for expected risk abatement, and the present value of a statistical life. Data on fatalities resulting from extreme weather events (droughts, floods, and heat waves) are available by country and year for 1960-2008. The observed climate fatality risk in a country at a given point in time reflects the interaction of weather patterns with a complex of capabilities and public/private benefit-cost calculations that vary by development level.

A climate risk function can be estimated from cross-country panel data for 1960-2008, using climate variables, income and country fixed-effects. The parameters of this function will reflect each country's unique combination of climate conditions, risk abatement costs and implicit valuation of a statistical life. Maintaining the current climate, the risk function can be used to estimate a baseline of weather-related fatalities in the future, as private and public agents in each country increase their risk reduction activities with rising incomes.

A changing future climate, however, will lead to changes in climate risks in each country. These risks can be translated to climate-related fatalities using the country risk functions. Comparing expected future fatalities with and without changes in future climate provides an estimate of additional fatalities related to climate change. When appropriately valued, this estimate can provide an important guideline for assessing adaptation policy in each country.

VI. Integrating the Top-Down and Bottom-Up Approaches

Integrating the two approaches. The difficulties of scaling up the results of the country case studies in order to generate global estimates of the costs of adaptation were highlighted in Section 1 above. One strength of this study is that it will yield global estimates of much greater coherence and plausibility than those which have been produced up to now. The country case studies, however, are more than just stand-alone exercises undertaken as a exercise in institutional development. They can be used to assess the potential scale of savings that can be made in adapting to climate change by adopting something other than a "one size fits all". The crucial gap between the global approach and the country studies is that between (a) doing the same things differently, and (b) doing different things. The history of economic policy is full of expected disasters that did not happen – the world did not run out of natural resources and billions of people have not starved.

The crucial lessons that can only come out of country studies concern the opportunities for adapting to climate change by changing anything from the structure and composition of agricultural output to gradually moving urban development away from flood-prone coastal and river plain locations. Of course, this may not happen in the short run – consider New Orleans – but our approach has to assume that sensible policies will eventually prevail in the face of the huge challenges of coping with climate change. Thus, setting the case studies against the global estimates for the same countries will provide an initial estimate of the potential gains that can be made via more intelligent forms of adaptation. The process of comparing bottom up and top down estimates is never simple because of the difficulty of ensuring that they work from common starting points. That is why the integration of the two approaches in the present study is so valuable.

It is also worth emphasising that all of our estimates – to the extent that they are comprehensive – are likely to overstate the ultimate costs of adaptation by a considerable margin. The cliché that necessity is the mother of invention is no less true for being much misused. Once the urgency of adapting to climate change is fully absorbed by both businesses and policymakers, past experience shows that there will be a sustained burst of innovation that will reduce the costs of constructing and operating climate resilient assets. At present, most emphasis is placed upon the development of low carbon technologies with varying degrees of success and economic viability. One of the more interesting benefits of the dual track approach in this study is that it can be used to identify and highlight the returns yielded by efforts to reduce the costs of incorporating climate resilience in new assets. For the most part this does not involve any substantial investment in invention – acquiring new knowledge – but rather the systematic application of technologies that exist but which are not universally or even widely used today.

VII. Limitations

The exercise of attempting to carry a systematic and wide-ranging assessment of the costs of adapting to climate change is an important and necessary one. But, without over-emphasising the obvious, it is equally important to recognize the limitations of what can be achieved in the country case studies and the global analysis. These are the first steps in a long process of understanding the responses that will be required to cope with the impact of climate change on developing countries facing different circumstances and opportunities. Our goal is to provide: first, a systematic framework for undertaking such assessments; and, second, an initial set of estimates that give a broad indication of the order of magnitude of the costs that may be involved.

To appreciate the uncertainties inherent in any such exercise we have tried to identify the major limitations of our analysis:

(a) ***Time horizon***. Setting a time horizon of 40-50 years ahead cannot be avoided because the errors in economic and other projections grow exponentially with the period considered. However, climate change will not progress at a steady rate, so there is a risk that important aspects of adaptation only impose a substantial burden in the second half of the current century. One option for assessing whether the choice of time horizon has a material impact on the conclusions is to consider what happens if agents look ahead 10, 20, 30, … years when developing building standards and scaling assets.

(b) ***Data availability and reliability***. The largest element of adaptation costs is a consequence of the impact of climate change on assets – in agriculture, water management and infrastructure. Unfortunately, by comparison with information on incomes and expenditures data on assets are notoriously incomplete and potentially unreliable, even for developed countries. For major sectors it is necessary to rely upon a very limited number of stock or flow indicators – numbers of doctors or teachers, hospital beds, students - as the basis for constructing estimates of the sectoral cost of adaptation. The best that can be done in this study is to use the limited resources of data in the most intelligent way and to highlight the areas in which better data might lead to significant improvements in the quality of the estimates. This is, of course, a particular problem for the global analysis because of the necessity of relying upon indicators that are widely available.

(c) ***Uncertainty and scenario analysis***. The approach relies heavily upon the examination of alternative scenarios for both climate change and economic development. Modeling and parameter uncertainty may average out when country estimates are summed to regional or global aggregates, but this does nothing to remove the uncertainty associated with extreme outcomes of climate change or unanticipated changes in long run rates of economic growth. In 1985 few would have predicted the sustained acceleration in world economic growth, especially in China and India that occurred in the following 20-25 years. Our crystal ball is likely to be equally cloudy. Thus, the assessments share the same uncertainties as the general range of models that are used for the analysis of climate change and its economic impacts.

(d) ***Integrating the country and global analyses***. Under the best of circumstances there would be an early iteration in which results from the global study are compared in detail with the results from the country case studies. This would provide a basis for refining the methods used in both approaches and improve the quality of both sets of estimates. While we intend to carry out such comparisons wherever possible, the delays in the country studies and the tight deadline for the global analysis will constrain what can be done by late summer. The same applies to the analysis of economic feedbacks that the country CGE models are designed to capture and which may apply at a global level as well. In essence, we are working with a framework that treats economic growth as being driven by exogenous forces and treats structural change as a (largely) deterministic consequence of economic growth. We intend that the CGE modeling will provide some insight into the cost reductions that may be possible when greater flexibility is permitted. The extent to which those cost reductions will scale up to the global level is very uncertainty because it depends upon the degree of international specialization and integration of world economic activity, something which is both highly contentious and very difficult to forecast.

Our work shares the strengths and weaknesses of economic models that fall in the general class of economic growth accounting. All of the conventional economic analyses of climate change fall into this category. We will provide a fuller degree of country and sector disaggregation, but at the expense of a less detailed analysis of specific aspects of the impact of climate change. Relative to other attempts to assess the cost of adaptation we believe that the major advance of this study is the development of a consistent framework across sectors and countries for constructing the estimates. In turn, this will allow us to make better use of the data that is available and to be clearer about the sources of uncertainty as potential feedbacks within our models.

VIII. Next Steps

Over the next year the EACC team will be working to complete both the global study and the country case studies and will do so to meet the following major deadlines.

Date	Deliverable
May 31	Preliminary Results on Global Estimate in time for

	Thirtieth Session of UNFCCC Subsidiary Bodies
July 31	Draft Report on Global Estimate of Adaptation Costs
November 15	Seven Country Reports + Final Report on Global Estimates
March 31	Final Project Report