The Economics of Adaptation to Climate Change

Draft Methodology Report
Annexes

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Annex 1: Some Conceptual Issues Related to Economics of Adaptation

Decision Rules under Risk and Uncertainty

Actions in policy making cannot be idiosyncratic; they must be justified in terms of clear decision rules. For example, ambient environmental standards do not simply "leap out of the science;" rather, while science is supposed to provide a probability distribution of the impacts on an exposed population, the actual choice between alternative standards must be based on a clearly articulated decision rule.

But there are competing decision rules that apply at project, program, and policy levels, and the choice between them also needs to be justified. In general, different decision rules reflect alternative normative ethical schools, and even approaches that are conventionally adopted, such as cost-benefit analysis (CBA),[1] do not necessarily reflect any universally accepted principles or consensus on an appropriate ethical norm, although CBA does relate to a <u>formal</u> ethical norm, the Kaldor Principle. Alternatively, there may be decision rules for which no formal ethical norm is available but that nevertheless reflect widely shared intuitions about appropriate public actions, e.g. the "maxi-min" and "mini-max" decision rules (see below). A choice between competing decision rules accordingly depends on the persuasiveness of the underlying normative ethic to the decision maker and ultimately to the stakeholders in the particular society.[2]

1. <u>Outcome- versus Process/Permissible-Based Criteria</u>: Decision rules, such as cost-benefit analysis, represent outcome-based or *teleological* criteria. In teleological ethics, the policy decision is made solely in terms of the consequences (to society generally or to particular publics) of the actions themselves. On the other hand, rules such as "prior informed consent" (perhaps involving agreed compensation for loss or damage experienced) are representative of process-based or *deontological* ethics. In deontological ethics, the specification of the process by which a particular policy action is accepted or rejected is the sole basis for deciding the correctness of the proposed action, and the actual consequences are irrelevant. Alternatively, actions may be viewed as good and proper in themselves, without regard to the outcomes or process by which the actions are agreed upon, e.g. a requirement of full and correct disclosure of the probable risks. These represent *axiological* criteria for decision making. Rights-based norms are generally deontological, since the notion of rights trumps cost-benefit considerations,[3] or, alternatively, axiological, since the nonviolation of rights is desirable in any case without particular regard to the consequences. Of course, not all claims would have the standing of a "right," and a societal consensus on exactly which claims have the standing of a "right" is essential.

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1 CBA, of course, reflects a particular normative ethic—i.e., the Kaldor criterion, which itself is an example of utility-based ethical norms.

2 This discussion is not carried to the next level of analysis—i.e., formal justification for the choice of the underlying normative ethic itself among competing ethical schools, which relates to meta-ethical criteria.

3 Thus the State would be justified in spending large resources to address credible threats to the life of a single individual without attempting to reckon whether the value of the individual to society is comparable or greater.

2. Examples of Outcome-Based (Teleological) Decision Rules

(a) Deterministic Cost-Benefit Analysis: The decision rules (based on the Kaldor norm) require the estimation of the benefits and costs of proposed actions (with practically certain outcomes, e.g. the output of a well-designed and engineered power plant) in subjective monetary terms—i.e., willingness to pay for received benefits and to be compensated for costs incurred or experienced. The alternative with the highest net benefit is chosen, provided that it is positive. Since there is no account taken of who benefits and who loses, the outcomes of the Kaldor-based decision rule may be highly regressive. Deterministic CBA is typically applied at the project level, although in concept there is no bar to its application at program or policy levels. In fact, a current requirement of U.S. environmental law is that all proposed legislation must be backed by a cost-benefit analysis of its consequences. Given the uncertainties inherent in assessment of climate change impacts, the deterministic form of CBA may have limited practical application.

(b) Probabilistic (or Expected) Cost-Benefit Analysis: This decision rule relates to situations involving uncertain benefits and/or costs of actions (e.g., protection measures against ocean surges in the context of climate change). The subjective monetary valuations of the benefits and costs of the actions are weighted by their respective probabilities, and the action with the maximum net expected benefit is chosen. This decision rule is also consistent with the Kaldor ethic; accordingly, the actual outcomes of chosen options may also be regressive. Moreover, it ignores the possibility that people may have valuations over the uncertain outcomes themselves, and not only manifested outcomes.[4] This decision rule, too, may be applied at project, program, and policy levels. A typical example of application of this decision rule at the project level in relation to climate change would be the design of seawalls for protection against ocean storm surges: the costs are those of construction and maintenance, with low uncertainty, while the benefits are lives and property saved, which are rather uncertain, given uncertainties in the probability distribution of storm surge events.

(c) Cost-effectiveness: This decision rule involves choosing a desired standard of risk abatement, e.g. protection from a flood with a 1% chance of occurrence in a given year, typically based on a political consensus in the given society, and choosing the policy alternative that meets the chosen standard at the least cost. Cost effectiveness may also be applied at project, program, and policy levels. In the preceding example, at the project level the decision rule would choose among various project types, e.g. dams, levees, embankments, etc., on the basis of the least costly intervention.[5]

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4 For example, people may be risk-averse and buy insurance. Alternatively, people may be risk-philic and gamble. Since the poor are generally more risk-averse than the rich, ignoring attitudes to risk involved in the expected cost-benefit criterion may enhance the regressive character of this rule.

5 The "cost" may, however, relate to economic, financial, or investment cost of the candidate interventions—these constitute variations on the basic decision rule.

(d) Bounded Cost: This decision rule refers to a society first identifying the level of resources it is prepared to devote to abating a particular societal risk, e.g. deaths from highway accidents, and then identifying the policy option from among the competing alternatives that achieves the maximum risk abatement. Typically, societies achieve lower levels of residual risk as they develop, reflecting the fact that development enables greater resources to be made available for societal risk abatement. This rule again may be applied at project, program, or policy levels. In the climate change context, an application may be the design, within a prespecified budget constraint, of a program of protection from sea level rise by choosing a set of projects that would maximize the *expected* benefits in terms of lives saved and property loss averted.

(e) Maximize Multi-Attribute Utility (MAU): The notion of multi-attribute utility recognizes that not all societal benefits and costs are commensurable with or reducible to monetary values. Accordingly, in this form of the utilitarian ethic, a utility function of the decision maker is evaluated for the entire range of significant outcomes (including uncertainties and risks) of different policy options, and the option with the maximum net utility is chosen.[6] In other respects, as well as situations where it may be applied, it is similar to (expected) CBA.

(f) Minimize Chance of Worst Possible Outcome ("Mini-max") or Maximize Chance of Best Possible Outcome ("Maxi-min"): These decision rules typically reflect political realities, in turn based on people's behavioral responses. Accordingly, following the occurrence of a rare catastrophe, governments may, responding to public fears, allocate far greater resources to abate the particular societal risk than would be justified, say, under an expected utility cost-benefit analysis.[7] In the context of climate change, the level of public expenditure and choice of interventions for a rural drinking water program may reflect a political imperative of avoiding deaths owing to shortage of drinking water under the worst plausible climate change scenario ("mini-max"). Alternatively, while devising a climate change adaptation program for agriculture, governments may promote C4 crops that can take more advantage of carbon dioxide (CO_2) fertilization than prevalent C3 crops, provided the new crops are otherwise suited to the changed climatic conditions ("maxi-min").

Numerous other outcome-based decision rules may be devised. For example, a non-utilitarian outcome-based ethic may seek to limit risk to non-human entities (e.g., tropical coral formations), and even non-living ones (e.g., Arctic ice), irrespective of their valuation by humans.

3. Examples of Rights-Based (Deontological or Axiological) Decision Rules

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6 MAU, however, relies on the assumption of a dictatorial decision maker, thus violating one of Arrow's conditions for existence of a "valid" social welfare function. It requires the explicit elicitation of attitudes to risk and uncertainty.

7 For example, following the catastrophic tsumani of December 2006, several Asian governments put in place costly programs to address the risks of future tsunamis, even though from historical experience a tsunami of that magnitude is likely a 1,000-year event, with expected costs far lower than those of the abatement programs.

(a) Zero Risk: This decision rule would proscribe the introduction of any *new* technological risks in society. Naturally occurring and old technological risks cannot be entirely eliminated, although they may be mitigated to an extent, but this decision rule argues that it does not follow that all new technologies bearing on societal risk must be deployed. In the climate change adaptation context, this decision rule may proscribe the introduction of genetically engineered crop varieties that may have been developed especially for the changed climate, on account of the novel risks that these crops may pose.

(b) Bounded (Constrained) Risk: This decision rule requires that irrespective of costs and benefits, the level of exposure to risk is to be bounded at a specified level; in turn, this level may be derived from socially determined criteria. This decision rule may be implicit in the prescription by some countries of a maximum level of 450 parts per million atmospheric concentration of CO_2 equivalent.

(c) Prior Informed Consent: Under this decision rule, the only risks that may be introduced are those permitted by the members of an exposed population that has full prior information about the nature and extent of risks; such consent may be in exchange for payment of agreed compensation. For example, this decision rule would permit the introduction of genetically engineered crop varieties in a given region if the (representatives of) members of the potentially exposed population give their consent, after a full disclosure of the risks and benefits of the crops, perhaps with an agreement on compensation levels in the event of the possible risks actually materializing.

(d) Approved Process: This widely used decision rule requires that the standard of risk be agreed through a legally specified due process. Any decision rule reached through the specified process must then be accepted by all concerned. Accordingly, the concerned law of a country may require the legislature of the relevant level of government to approve programs to address climate change risks; such decision would then bind all concerned.

Other rights-based criteria may be devised. For example, a (welfarist) Rawlsian decision rule would require an overall improvement in social welfare, together with the requirements that the welfare of all must increase and that of the poorest in society must increase the most.[8] Accordingly, a cyclone-prone country may, for protection against enhanced cyclonic conditions under climate change, adopt a cyclone protection program that would provide increased protection to all but that may be deliberately biased in favor of greater protection for poor fisherfolk than for better-off urban residents.

4. Technology-Based Criteria: A further genus of decision rules are based on technological criteria. One widely cited rule is that of the "best available technology" (BAT). This rule requires the abatement of risks to the maximum extent possible with current technology. In practice, this rule is applied with the rider that the technology must meet some

8 Despite the strong nature of end-result required by Rawls, the ethic is classified as deontological owing to the fact that it derives from certain strong process assumptions.

specified test of "affordability."[9] In the context of climate change, this decision rule may require, for example, that the technologically most effective option may be employed for conservation of water resources, irrespective of cost-benefit considerations.

5. Hybrid Criteria: Frequently decision rules are a hybrid of different approaches. For example, in the context of climate change, a public health program may prescribe that the increased overall risk of morbidity be bound to a given level, while individual projects within this overall constraint—say, control of malaria, prevention of water pollution, or alternative drinking water sources in coastal areas subject to salinization—be given priority and chosen on an expected CBA criterion.

Treatment of Time Horizon and Inter/intragenerational Equity

Much has been written over the last decade on the issue of discounting in the context of global climate change mitigation policy (see, for example, Portney and Weyant 1999, Stern 2007, and Weitzman 2007). Discounting is an issue of particular concern on adaptation to climate change because it involves investments for which costs are incurred in the near term (during the lifetime of the current generation) while benefits are expected to accrue over the long term—which could be decades or centuries in the future. Discounting allows policy makers to convert costs and benefits at different points in time into comparable costs and benefits at a single point in time. Such cost-benefit analysis is, however, highly sensitive to the choice of the discount rate, especially when net benefits are relatively long-term, since even small changes in the discount rate can have a large effect on the ranking of different investment projects.

Discounting for Near-term CBA
One important determinant of the appropriate discount rate is the time horizon over which benefits are realized and costs are incurred. For a number of adaptation projects, costs and benefits are distributed in the near term. As argued by Stern (2007) and many others, if a project's costs and benefits affect only the current generation, then it is reasonable to apply the discount rate as revealed by societies' preferences in allocating its consumption and investments. This puts the choice of discount rate firmly in the "descriptive" (one based on revealed preferences) as opposed to "prescriptive" (one based on ethical considerations) camp (see Arrow et al. 1996). Furthermore, to the extent that benefits and costs affect only populations within a country, which is the overall case of adaptation to climate change, it is reasonable to apply the discount rate as revealed by a country's preference in allocating its consumption and investments. The literature on cost-benefit analysis contains a number of different suggestions on appropriate discount rates, as described in this section.

Marginal Productivity of Capital in the Private Sector: Some suggest that this rate should be used to discount all investments, both public and private, to ensure that only projects with the highest return are undertaken. Specific market rates that reflect the marginal productivity of capital, in turn, are: (a) real pre-income-tax rate of return on private company stocks and (b) real post-income-tax rate of return on private company stocks.

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[9] For example, emissions standards from industrial plants are frequently set on a BAT basis with a stipulation that abatement measures should not exceed, say, 3% of the capital costs.

Accounting Rate of Interest: This is the estimated marginal return from public sector projects given that a fixed amount of investment funds is available to the government. This ensures that the best public sector projects are undertaken within a given budget. The use of this rate, however, does not ensure that resources are optimally distributed between private sector and public sector projects.

Opportunity Cost of Funds Obtained from the Capital Market**:** This rate is a weighted average of the marginal productivity of capital in the private sector and the social rate of time preference for consumption. As discussed by Hamilton (2008), "government borrowing in the capital markets imposes opportunity costs on current savers and investors." Borrowing for the marginal project can be expected to raise the market interest rate and thereby to stimulate savings and impose an opportunity cost in terms of forgone consumption and also reduce private investment and impose a cost in terms of forgone profits. The economic opportunity cost of capital captures these effects. Belli et al. (2001) provide an estimate for the opportunity cost of capital, which depends on the amount of private savings (S), private investments (I), after-tax return on savings (r), and before-tax return on investments (R):

$$OCC = r\left(\frac{S}{S+I}\right) + R\left(\frac{I}{S+I}\right)$$

A number of studies that have estimated the economic opportunity cost of capital put this rate in the range of 10–12%. This also happens to be the range within which the default rate used by the World Bank for its project economic analysis falls, leading some to conclude that the default rate could be interpreted as the economic opportunity cost of capital (Hamilton 2008).

Social Discount Rate: This term is widely used in the literature on discounting and by and large means two things. When projects costs and benefits fall only on the current generation, the term captures the rate at which society (as opposed to the individual) discounts consumption over time. Some have argued that the economic opportunity cost of capital, a market rate, reflects purely private preferences for consumption. For public sector projects it may be more appropriate to use a lower discount rate or the social discount rate as (a) there is less of a case for governments to be impatient; (b) risks to society as a whole are lower; and (c) capital markets reflect private preferences over a relatively short term. One possible candidate for the social rate of discount is the real rate of return to government bonds. On the other hand, and in the context of intergenerational cost-benefit analysis, the social discount rate is said to equal the sum of the pure rate of time preference and the coefficient of relative risk aversion times the per capita growth rate of consumption (a la the Ramsey Rule) and to reflect the trade-off between the well-being of the current generation and that of future generations.

Though not explicitly stated, the World Bank's use of the economic opportunity cost of capital, a relatively high discount rate, as its default rate is justified on the grounds that it allows the Bank to ration development funds and moreover to invest in projects with the highest returns. This rationing is justified in the context of IDA funds, but perhaps not for IBRD funds. It is common in developed countries, for example, to use different rates for public and private sector projects[10].

Alternatively, as argued by Weitzman, "[t]he issue of which rate of return to choose (as between [risk-free or the economy-wide return on capital]) for discounting a project comes down to the extent to which the payoffs from the project are proportional to or independent from returns to investments for the economy as a whole" (Weitzman 2007, p. 711).[11]

More important, though, this study has been tasked with estimating what it would cost developing countries to adapt to climate change. Investments in adaptation are likely to be similar to investments made in other public sector projects that try to deal with current climate variability. This then argues for using the discount rate, or project evaluation framework, used in the country to evaluate public sector investments as the rate or evaluation framework for the study.

Discounting for Inter-generational CBA

So far the assumption has been that the benefits to adaptation policy are likely to be local and immediate. This, however, need not always be the case. Investments in embankments or seawalls to protect against sea level rise are expected to yield benefits in the long term, not just the near term.[12] This is also likely to be the case for investments in biodiversity conservation.

Stern (2007) and others have argued that when benefits and costs affect not just the current generation but future generations as well, revealed discount rates are not appropriate for CBA as these only reflect the preferences of the current generation. Moreover, as argued by Sterner and Persson (2007), revealed discount rates reflect what *is* and not what *ought* to be. Choice of the appropriate rate of discount then becomes an ethical issue. Based on the famous Ramsey formula ($r = \delta + \eta.g$), the ethical issue comes down to the choice of two parameters – the rate of pure time preference (δ) and the coefficient of relative risk aversion (η), with g denoting the per capita growth rate of consumption.[13] A low value of δ implies intergenerational equity, while a high value of η implies intragenerational equity. These parameters must however be chosen in order to determine the appropriate rate of discount for long-lived adaptation projects. (See Box 1.1.)

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[10] For example, the United States Government's Office of Budget and Management recommends the use of the real pre-tax rate of return on private company stocks (that is, the real rate of return on investments in the private sector) for standard cost-benefit analysis and a lower rate, typically the U.S. Treasury's borrowing rate—the real rate of return to government bonds—for public investments. Between 1929 and 1990, while the real rate of return on investments in the private sector was approximately 7% for large companies in the United States, the real rate of return to government bonds was approximately 4%.

[11] So, for example, if the benefits of adaptation to climate change are modeled as a decline in the proportion of total output lost due to climate change, then payoffs are considered to be proportional, and an economy-wide return on capital is then the appropriate discount rate. If, on the other hand, damages due to climate change, and hence benefits from adaptation, are specified as being additive with gross domestic product or as entering the utility function as a direct argument, then the risk-free rate should instead be used to discount projects.

[12] In this context, and as analysts flush out adaptation options and undertake their cost-benefit analysis, policy makers need to understand the extent to which benefits are intergenerational given that benefits are tied to the lifespan of a project.

[13] According to Weitzman (2007), the per capita growth rate of consumption is a reduced-form representation of technology.

Box 1.1: Choosing the Rate of Discount and the Ramsey Formula

The rate of pure time preference reflects the trade-off that ought to be made between the well-being of future generations and that of the current generation. A rate of pure time preference equal to zero implies that placing the same value on the welfare of future generations as on this one, while a positive value implies that the welfare of future generations is discounted. A number of economists have suggested that this rate be set to zero, though others have strongly disagreed with this statement. Stern (2007), for example, sets this rate at 0.1 to reflect the possibility of extinction but implying no inherent discrimination against future generations. Others have argued for a higher rate.

On the other hand, the coefficient of relative risk aversion is a "measure of the aversion to interpersonal inequality and risk in consumption" (Dasgupta 2007, p. 4). A low value of η (which is usually assumed to lie between 1 and 4, though experimental economics asserts that $\eta \in [2,4]$) implies that "distribution of well-being among people doesn't matter much, that we should spend huge amounts on later generations even if they are expected to be much better off than us" (Dasgupta 2007, p. 7). In other words, a low coefficient of absolute risk aversion implies that even the poor in the current generation must be asked to sacrifice for the welfare of future generations. Using the Ramsey Growth Model, Dasgupta (2007) goes on to show that $\delta=0.1$ and $\eta=1$ imply the current generations should be saving 97.5% of their aggregate output for the future. When $\eta=3$, on the other hand, it implies a lower, and some would argue more reasonable, savings rate of 25%.

Declining Discount Rate

Another issue in the literature on discounting merits some discussion: declining discount rates. It may be reasonable to have constant short-term discount rates up to a period beyond which financial markets do not reveal expectations about future rates, perhaps 30–40 years at most, and a lower rate thereafter. The literature justifies this approach in a number of ways. For one, analysis of how people actually discount the future (using experimental economics or ex-post cost-benefit analysis of public sector projects with intergenerational benefits, such as the Suez canal) suggests that discount rates decline as time goes on or that discounting is hyperbolic rather than exponential (Fredrick et al. 2002). Similarly, uncertainties about future interest rates along with the fact that interest rates are highly persistent also imply that interest rates decline over time, and in the limit (as $t \rightarrow \infty$) discount rates converge to the lowest possible discount rate (Weitzman 2001 Newell and Pizer 2001). Finally, with uncertainty about future incomes another effect becomes important—namely, the prudence or precautionary savings effect: when people are unsure about future income, they save for a rainy day. This effect lowers the discount rate and implies a decline in the long-run discount rate (Gollier 2002). The use of time-varying discount rates, however, leads to time-inconsistent behavior.

Equity Weights and Appropriateness of CBA

So far we have discussed issues of equity in the context of discounting and intergenerational cost-benefit analysis. Concerns about equity arise in two other contexts: (a) aggregation of costs and benefits when groups within a generation differ by income levels and (b) appropriateness of CBA when costs and benefits of a project are unequally distributed within a generation (or across generations) or when damages are expected to be catastrophic in nature.

Given that costs and benefits of a project are measured in terms of willingness to pay and that willingness to pay is determined by an individual's socioeconomic characteristics, in particular income, estimates of the costs and benefits of a project will differ by socioeconomic groups, since people will place different values on otherwise identical goods such as, say, a given reduction in mortality risk. The question then arises, how should policy makers aggregate over these differences to estimate the aggregate costs and benefits of a project? Fankhauser et al. (1997) argue that if the underlying income distribution 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 an equity weight in the aggregation process. The equity weight, in turn, is inversely related to the person's per capita income and is equal to the ratio of average income to the individual's income. The ethical judgment in such aggregation processes concerns the choice of the social welfare function used to aggregate individual cost-benefit estimates.

To summarize, in the realm of intergenerational cost-benefit analysis or when the underlying income distribution is considered to be unfair, estimating individual net benefits from a project and aggregating these estimates requires a number of ethical judgments, be it concerning the value of the coefficient of relative risk aversion or the type of welfare function used in aggregation. In the interest then of consistency of methodology across country case studies, sensitivity analyses that allow for a range of ethical values may be undertaken. Alternatively, policy makers may want to choose values for such parameters that reflect the ethical choices of their society.

Another issue surrounding equity relates to the Kaldor-Hicks compensation principle, which states that if those benefiting from a project can, in principle, compensate the losers and still gain in the net, then the cost-benefit criterion is said to be satisfied. There is a potential ethical concern here because no actual compensation need be paid by the gainers to the losers. The question then arises, should policymakers use cost-benefit analysis to evaluate adaptation projects if the costs and benefits of the project differ by socioeconomic groups and there is no mechanism by which the winners can compensate the losers? This in the least argues for careful tracking of how costs and benefits are distributed across socioeconomic groups.

In addition, concerns about equity and appropriateness of CBA also arise in the context of high-damage (or catastrophic) but low-probability climate-change-induced events. Lind (1995), for example, poses the question as to whether current generations should invest in climate change abatement projects on the grounds of intergenerational equity, irrespective of the cost-benefit criterion. This depends on whether per capita income is expected to continue to grow in the future and the expected magnitude of the costs imposed by global warming. If in fact future generations are expected to be worse off than current generations on account of the costs imposed by global warming, then a case can be made for current generations subsidizing future generations. However, most economic models indicate that only if there are catastrophic greenhouse gas effects will future generations be worse off than current generations, suggesting, in turn, that cost-benefit analysis may not be appropriate when analyzing high-damage, low probability events.

Similarly, analysis by Weitzman (2007) suggests that the marginal approach of cost-benefit analysis may not appropriate for catastrophic events. In the context of uncertainty of climate change, it is the high-damage but low-probability events that need to be the primary focus of policy makers, and their main concern should be "how much insurance to buy to offset the small chance of a ruinous catastrophe" (Weitzman 2007, p. 705). Benefit cost analysis is not an adequate tool to evaluate these projects.[14]

Environmental Services and Nonmonetary Issues

Climate change adaptation strategies often change the goods and services derived from ecosystems by people. Ecosystem services are the benefits people obtain from ecosystems. These include provisioning of food, fiber, fuelwood, freshwater, and genetic resources; regulating climate and disease; pollination and water purification; and cultural services (such as spiritual enrichment and aesthetic experience) that directly affect people and supporting services (nutrient recycling, coil formation, and primary production) needed to maintain the other services (MA 2005).

An adaptation strategy or project often provides multiple benefits. In evaluating such strategies it is important to include total value associated with all the different costs and benefits of the strategy or project. For instance, protecting a forested area can simultaneously provide timber for loggers, ecosystems services for local communities, water filtration for hydroelectric plants, preservation of biodiversity, genetic resources for multinational pharmaceutical companies, and carbon sinks for global CO_2 emissions.

Adaptation strategies and decisions that fail to value all ecosystem services will not be optimal. For example, strategies that exclude the health effects of water pollution on downstream populations would result in excessive water pollution. Similarly, if trees were planted based on their aesthetic and recreational values alone while ignoring their environmental benefits as windbreaks and conservers of water and wildlife habitat, there would be an underinvestment in planting trees.

The social welfare gains from a specific adaptation strategy can often be difficult to identify and measure, especially when they include ecosystem services. When ecosystem services are traded

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[14] Weitzman (2007) suggests that the marginal approach of cost-benefit analysis may not appropriate for catastrophic events. In the context of climate change, there is uncertainty (à la Knight) about the scale and probability of high-damage but low-probability events. There is just not enough information from the past to calibrate sample frequencies. This uncertainty, in turn, implies that the growth rate of per capita consumption needs to be seen as a random variable whose probability distribution has a climate-change-thickened left tail that carried most of the weight of the expected utility in cost-benefit analysis. It is these high-damage but low probability events that need to be the primary focus of policy makers. As a result, policy makers need to pose climate change as an issue of "how much insurance to buy to offset the small chance of a ruinous catastrophe" (Weitzman 2007, p. 705). This formulation gets away from ethical choices about rate of pure time preference, coefficient of relative risk aversion, etc. When applied to adaption policy, Weitzman's hypothesis would suggest that for low-probability, high-damage events the issue to consider is how much to invest in either exposure reduction (ex-ante or anticipatory investment) or damage insurance (ex-post impact mitigation or reactive investments) to reduce the damage due to these events to some acceptable level of risk, rather than applying standard cost-benefit analysis to evaluate such projects.

(e.g., commercial resources, such as timber), the market prices can be used to infer people's willingness to pay for them. In other cases it may not be as easy. Ecosystem services such as better water filtration for local communities or hydroelectric plants are not sold or bought in any market, so no price exists for them. Likewise, there is no explicit trade in landscape beauty or the preservation of culture or natural heritage. One reason some environmental goods are not traded is that they are public goods, meaning that it is impossible or technologically very difficult to charge a price for their consumption.

The use of environmental resources or services can provide value (a) directly through the consumptive (logging for fuelwood, fishing for subsistence) or nonconsumptive (recreation value of a park or coastal area) use of the resource, (b) indirectly through the use of resources' services (watershed protection services of a forest), or (c) through the option of providing for potential future use of goods or services (conservation of a natural habitat can preserve the option of transforming it in the future based on new information that may only be available at that time). Environmental resources can also provide two types of non-use values that indicate a social willingness to pay for a resource regardless of its current or future use. Such values may arise because of altruism toward future generations (bequest value) or because of the simple knowledge that something exists (existence value) even if individuals never plan to use it.

There are two broad approaches for determining the value of environmental benefits when they cannot be directly observed: the damage function approach and the human behavior approach. Several techniques have been developed under each approach.

The damage function approach first estimates the physical adverse impacts (cases of illness avoided) of the environmental change (expansion in the malaria transmission range), which are then valued at a unit price (hourly wage of the ill). One limitation of this approach is that it does not directly answer how much people are "willing to pay" for avoiding the damage. Willingness to pay, or a lower bound of it, is instead inferred from existing prices. Its primary advantage stems from the separation of the "hard science" from the valuation. This approach does not require people to understand the epidemiology or atmospheric chemistry linking the adverse impacts to the environmental change.

The human behavior approach, on the other hand, infers willingness to pay to avoid the adverse impacts directly from people's behavioral reaction to the environmental change, regardless of the existence of an impact, such as a change in health or productivity. For example, individuals can purchase bottled water or migrate to areas with cleaner water in response to changes in water quality. The value of clean water can be inferred from the observed averting behavior even when the specific adverse impacts cannot be quantified. Similarly, the cost to travel to a recreational site has been used to value the benefits derived from such a site. The hedonic price technique decomposes the price of a good such as a house into its various attributes. It is used to infer the social willingness to pay for improved local environmental quality by comparing the prices of houses similar in all aspects except the environmental attribute.

In some cases preferences cannot be observed either in the marketplace or through some implicit price of related marketed goods, or they are difficult to obtain. The contingent valuation method (CVM) uses surveys to elicit values by directly asking people what they would be willing to pay for the goods or services in these instances. CVM is particularly useful to ascertain non-use values which, by definition, cannot be revealed from any type of behavior. Consider, for instance, the value of the "tiger." No markets exist to buy or sell tigers, and few people go all the way to India to see one. Still, conservation groups have been raising funds for their protection. People are indeed willing to pay simply for the existence of an environmental good or service or a natural resource, regardless of being able to ever use or directly enjoy it.

Timing of Investments

The timing of adaptation investments should be determined by six factors: (a) the expected timing of the impact of climate change on the economy, (b) the effect of scientific and technological progress on the productivity of adaptation investments, (c) the effect of technological progress on reducing the uncertainty of climate change, (d) irreversibility in the costs of adaptation, (e) the social discount rate, and (f) considerations of cash flow and financing of the government's investment package. Under any positive rate of time preference (or positive rate of financing of government's deficit), government prefers to defer the investment in adaptation until as late as possible, providing the investment is made in time to provide the necessary protection against changes in the climate. Thus, for example, if it is known with certainty that a 1,000-year storm will strike in 2058, a rational government will time the seawall to be completed in, say, 2057 to avoid the opportunity cost of having capital unproductively tied up in a seawall built earlier than necessary. In the real world, however, the date of arrival of a 1,000-year storm is unknown. What is known is that the storm that was expected with a frequency of only every 1,000 years prior to the increases in atmospheric greenhouse gases is now expected with greater frequency—how much greater is not yet known with any reasonable degree of certainty.

The rate of progress in climate science has been rapid, however. 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 seawall 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.

In making decisions regarding adaptation investment, especially protection against extreme events, governments face two types of potential errors. To return to the example of a 1,000-year storm, government can fail to build the seawall before such a storm occurs (type I error). Or the government builds a seawall and the storm fails to occur during the lifetime of the seawall, or the government builds the seawall and then learns that the impact of climate change on sea level rise will not be as high as expected (type II error). Ideally government would like to minimize the sum of the probabilities of both these errors.

Another way to pose the problem of optimal timing of investment is by drawing on the literature in environmental economics on investment decisions under uncertainty, irreversibility, and learning. This literature, in turn, has established that by and large it is optimal to delay (though not necessarily rule out) investments in projects that irreversibly damage the natural environment—such as projects that irreversibly convert wildlife habitats into farmlands (or alternatively, to advance investments in projects that help protect the environment, such as projects that reduce greenhouse gas emissions and limit the accumulation of irreversible stocks of these gases)—if the future net benefits of the project are uncertain, if the impacts on the environment are irreversible, and if there is a possibility of learning about future net benefits. One condition under which this so-called irreversibility effect fails to hold is when consumer preferences are characterized by low elasticity of intertemporal substitution or a high coefficient of relative risk aversion. With a relatively high value for the coefficient of relative risk aversion, a value that would support intragenerational equity concerns, it may instead be optimal not to delay investments in projects that irreversibly damage the environment or not to advance investments in projects that protect the environment from irreversible damage.

For timing of investments in adaptation projects, the literature suggests that 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 in adaptation projects that are sunk 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 seawalls, which are essentially sunk investments, should be delayed (though not necessarily eliminated). Were it to be the case that the rise in sea levels is not as high as previously expected, then investments made in seawalls could result in wasted resources, as once invested in seawalls 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, investment in mangroves that helped protect against the impact of sea level rises but also provide current development benefits need not be delayed. For if it were to be the case that mangroves are not needed to adapt to climate change, resources invested in mangroves would still have been used for development.

Waiting can be introduced into the model by creating a fund that can be drawn down in the future. This permits sensitivity analysis on the rate of technological progress in adaptation technology and climate forecasting.

Annex 2: Climate and Hydrology

Climate

The spatial and temporal pattern of temperature and precipitation is often used to describe the climate of a given area at a point of time. One of the most widely used approaches to represent possible climate futures at regional or local scales combines two large databases that describe historical patterns of temperature and precipitation and projected future patterns of these same indicators.

The first database—from the Climatic Research Unit (CRU), University of East Anglia, UK—developed by an international consortium led by NASA combines temperature and precipitation measurements at local weather stations over the past century with satellite observations of local climatic conditions to develop a digitized global map of historical monthly temperature and precipitation data. The CRU dataset provides the best representation of ground-level historical climatic patterns by drawing on actual measurements from weather stations where available. It uses satellite-based observations of broader climatic patterns to spatially interpolate the historical observations for areas with sparse weather stations. The result is a global digital map, with monthly temperature and precipitation at a spatial resolution of 0.5^0 by 0.5^0, approximately 50 km by 50 km. The time series from the CRU database is useful for trend extrapolation and may actually be preferred for short-range local climate forecasts.

The second database consists of simulation outputs from a variety of General Circulation Models (GCM)-also known as Global Climate Models-that have been developed by research institutions around the world. Currently climate futures are available from about 20 such models. These computation-intensive models provide spatially integrated climate forecasts, within some range, from changes in atmospheric greenhouse gas concentrations that are projected by the Special Report on Emissions Scenarios (SRES) (see Box 2.1) of the Intergovernmental Panel on Climate Change (IPCC). The models are typically calibrated by backcasting to the recent past.[15] Climate outcomes from GCMs incorporate the effects of future carbon emissions, hence they will play the dominant role in the long term. However, they are only able to provide climate outcomes at a coarser resolution because of their focus on spatially integrated global modeling.

The two datasets can be combined to develop a spatially disaggregated database that tracks monthly observations on temperature and precipitation from the past to the current based on the CRU data and from the current to the future based on projections from the GCMs. Maintaining consistency across time and space in the hybrid dataset is computationally intensive.

[15] At present, multi-model, multi-emission scenario projections are available for several climatic parameters including: Mean Temperature, Temperature Extremes, Mean Precipitation, Precipitation Extremes and Droughts, Snow and Ice, Carbon Cycle, Ocean Acidification, Sea Level, Sea level Pressure, El Nino, Monsoons, Tropical Cyclones, Mid-latitude Storms, among others.

Box 2.1: SRES Climate Scenarios

Adaptation requires understanding the potential impacts of climate change on human, economic and ecological systems. Yet attempts to estimate such impacts have to take on the cascade of uncertainty illustrated in Figure 1.2. Uncertainty starts with the selection of an appropriate underlying emission scenario which is determined by economic and population growth, and by energy use choices. Will the world grow rapidly or slowly? Will developing country populations soon adopt the consumption habits of high income countries? And what kind of energy future are we to look forward to? To account for these questions, the IPCC has developed 6 socio-economic scenarios that characterize possible trajectories of population and economic growth and the degree of adoption of clean technologies.

A scenario is a coherent, internally consistent, plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold, given a specific set of assumptions described in a set of four narrative storylines for the climate scenarios: A1 (focused on economic growth and globalization), A2 (regional focus), B1 (focused on environment), and B2 (regional focus). These assumptions include future trends in energy demand, emissions of greenhouse gases, population and economic change, technology, and land use change as well as assumptions about the behavior of the climate system over long time scales. It is largely the uncertainty surrounding these assumptions that determines the range of possible scenarios. According to the IPCC, all families of scenarios from each storyline are equally valid, with no assigned probabilities of occurrence. Although the SRES scenarios have come in for some criticism for population and economic details, the scenarios are internally consistent and constitute a useful set of standards.

The choice of climate and related non-climatic scenarios is important because it can determine the outcome of a climate impact assessment. Ideally, the scenario of choice should reflect more detailed regional development projections regarding social, economic, and technological pathways or should cover most of the range of projected temperature change. According to the IPCC, however, all scenarios have more or less the same projected temperature increase up to 2050 (a time frame arguably more relevant for adaptation), even though there are large uncertainties regarding carbon dioxide emissions within each particular scenario. Therefore, the selection of a particular or several scenarios for this study will depend largely on the availability of GCM data as well as some range of most "likely" future scenarios for the location of interest. Most of the GCM data currently available are for the most moderate storyline markers scenarios (e.g. A1B—balanced across energy sources). However, new studies suggest that current CO2 emissions may already surpass estimates for even the most liberal scenarios. Therefore, in order to deal with uncertainty, it is best to use information from more than one scenario and climate projection.

Future climate scenarios can be constructed with hybrid projection models using outputs from one or more of the currently available GCMs. The specific GCM that will be used can be determined by a goodness of fit measure of the backcast outputs with respect to corresponding historical climate data for the relevant area. Variation in the climate outcomes, including derived indicators such as the incidence of extreme events, projected by different GCMs under a range of future emissions scenarios can be used to test the robustness of the analyses.

Hydrology

Future changes in climate are also predicted to affect hydrology, with significant potential impacts on different economic sectors (Bates et al. 2008). Example of changes in hydrology include:

- *Annual average river runoff and water availability* are projected to increase as a result of climate change at high latitudes and in some wet tropical areas and to decrease over some dry regions at mid-latitudes and in the dry tropics.
- *Changes in the seasonal response of the discharge hydrograph* are expected in some regions, such as increased wet season runoff and decreased dry season runoff. A very robust finding is that warming will lead to changes in the seasonality of river flows in areas where much winter season precipitation currently falls as snow, with spring flows decreasing because of the reduced or earlier snowmelt and with winter flows increasing.
- *River discharges of rivers draining areas covered by glaciers or snow* may increase and experience changes in seasonality in the short term as the cryosphere responds to warming and may decrease in the longer term as the area and volume covered by glaciers of snow is reduced.
- *Potential evapotranspiration is projected to increase* almost everywhere as the water-holding capacity of the atmosphere increases in response to higher temperatures. However, changes in actual evapotranspiration over land may increase or decrease depending on local-scale changes in soil water conditions and land cover, which are themselves influenced by climatic change.
- *Annual mean soil moisture* is projected to decrease in the sub-tropics and the Mediterranean regions and at high latitudes where snow cover diminishes. Soil moisture is projected to increase in regions with increased precipitation.
- *Groundwater levels in shallow aquifers will be affected by changes in climate via the recharge process* (Chen et al. 2002). However, to date knowledge of current recharge rates and groundwater levels is poor, and little is know of the impacts of future climate change.
- *Many forms of water pollution are expected to be exacerbated* by higher water temperatures, increased precipitation intensity, and longer periods of low flows, such as sedimentation, nutrients, dissolved organic carbon, pathogens, pesticides, salinity, and thermal pollution.

The impacts of changes in hydrology will be felt in a number of other sectors, such as agriculture, health, fisheries, biodiversity, forestry, urban infrastructure, transport, tourism, and industry. A few examples of these impacts are:

- *Agriculture:* Changes in river discharge can affect the potential for irrigation schemes and the systems used for irrigation; changes in soil moisture and water availability may affect crop yields as well as the productivity of livestock; changes in the frequency and timing of droughts can be critical determinants of agricultural productivity.
- *Health:* Changes in water availability and quality due to changes in river flows, the hydrological cycle, and rates of extraction are important determinants of waterborne diseases, particularly of children and infants.

- *Fisheries:* In estuarine regions and deltas, changes in freshwater availability due to changes in annual discharge and the seasonal distribution of discharge can have substantial effects on fish stocks.
- *Biodiversity:* The ability of species to survive in various areas is in large part dependent on water availability and the hydrological cycle. Wetlands, which are frequently biodiversity hotspots, are particularly sensitive to changes in the input of freshwater.
- *Forestry:* Forests and water have strong relationships with each other. A change in soil moisture availability will affect forestry yield, forest type, etc.; changes in the forest area can in turn have significant effect on both mean discharge (mainly through changes in actual evapotranspiration) and flooding.

Given the importance of water needs in defining a wide range of sector-level exposures, it is imperative to have a thorough understanding of how changes in climate have already affected hydrology and what effects can be expected in the future. Changes in freshwater resources can be assessed by (a) examining trends and patterns over the last century and the last decennia using observed records, (b) simulating the projected changes in the coming century, and (c) reviewing literature and expert judgments relating changes in climate and water quantity to changes in water quality. These three approaches are discussed in this section.

Historical Data

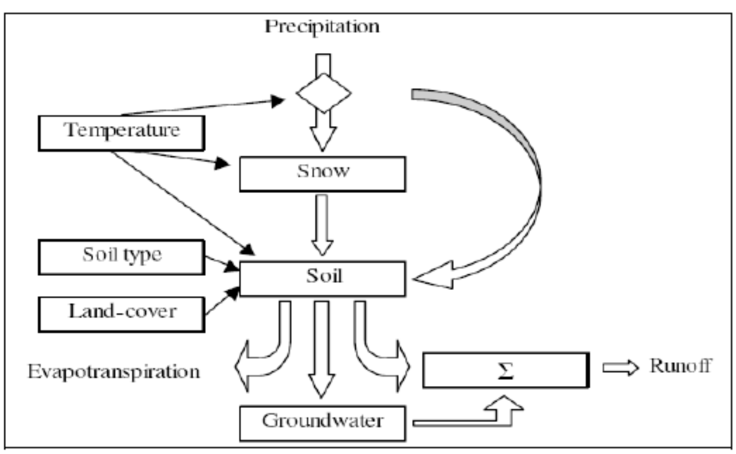
In many parts of the world, measurements of various hydrological parameters have been made for a number of years. In most cases these measurements are restricted to those on discharge (in some cases monthly, in some cases daily) at given locations. Where these data are available for relatively long periods (e.g., > 30 years) they can be used to give an indication of the variability of discharge in terms of current (and recent) climate conditions. In some cases the observed discharge data may already reveal statistically significant trends of increasing or decreasing discharge. These data are also necessary for the calibration and validation of model performances for the simulation of future changes. The availability of data is strongly dependent on the country and region of study, although large databases are available at the global scale. Examples include the RivDIS database (Vörösmarty et al. 1998) and the SAGE database of the Center for Sustainability and the Global Environment. Apart from these datasets, data for various river basins may be available within the case study countries.

Future Projections

For some countries, detailed simulations of the response of the hydrological system to climate change may already be available. Hence, the first step in this part of the study will be to carry out extensive literature reviews within the case study countries to identify existing simulations that already provide detailed assessments of the potential future changes in key hydrological parameters. For example, a hydrological model has been used by Mirza et al. (2003) to examine the impact of climate change on river discharges in Bangladesh, including possible changes in the magnitude, extent, and depth of floods of the Ganges, Brahmaputra, and Meghna rivers. The assessment was done using a sequence of empirical models and a hydrodynamic model (MIKE11-GIS), together with various climate change scenarios. Changes in land inundation will have significant implications on rice agriculture and cropping patterns in Bangladesh. Where such assessments are currently missing, the data will be supplemented by performing new hydrological simulations.

Changes in hydrology and water availability over the coming century as a result of climate change can be divided into changes in the *supply* of water to the hydrological system (i.e., due to changes in precipitation and temperature) and changes in *demand.* Modeling studies can be used to simulate the effects of future climate change on water supply at the regional water basin level. Runoff is a direct output of GCMs, although the coupling of climate models with hydrological models provides more realistic results.[16]

Many models exist to simulate the hydrological cycle at a range of temporal and spatial resolutions. The concepts used in hydrological models reflect the application for which the model will be used, and since the range of applications is large, so too is the range of modelling concepts. In this study it is proposed to use the STREAM rainfall-runoff model (Aerts et al. 1999). STREAM is a grid-based spatially distributed water balance model that describes the hydrological cycle of a drainage basin as a series of storage compartments and flows. Some of the main advantages of the model for use in participatory modeling exercises are that it is designed for use with Windows computers and has a user-friendly interface and easy-to-learn scripting language, which allows any scientist to use it. Furthermore, the spatially distributed raster approach allows for the modeling of spatial changes in parameters such as land use and soil characteristics. With the correct data, any basin across the world can be modeled, and the choice of spatial resolution can be tailored to the desired study. The main flows and storage compartments used to calculate water availability per grid cell are shown in Figure 2.1. The direction of water flow between grid cells is based on a digital elevation model (DEM). STREAM (or its predecessor RHINEFLOW) has been successfully applied to numerous basins of varying sizes in different parts of the world, including the Rhine in Europe, the Ganges-Brahmaputra and Krishna in India, the Yangtze in China, and the Perfume River in Vietnam, and is currently being used to assess changes in freshwater availability in the Bay of Jakarta (Indonesia).



[16] Runoff estimates from GCMs need to be interpreted with a great deal of caution for a number of reasons. Within GCMs, runoff is generated when either (a) rainfall intensity exceeds soil moisture infiltration capacity, or (b) rain falls on saturated soils. In general, the land surface parameterization does not represent the sub grid cell spatial variation in soil and vegetation properties, thus limiting GCMs' ability to simulate runoff realistically.

Figure 2.1: Flowchart showing the main storage compartments and flows of the STREAM model (from Aerts et al. 1999)

The input data required to run the model are:

Climate data: These are maps of (monthly) precipitation and temperature. Simulations of these parameters are available for the globe for different SRES climate change scenarios based on GCM runs carried out for the IPCC AR4. The climate data obtained directly from GCMs are too coarse to be used directly in (regional) hydrological simulations (Arnell et al. 1996, Xu 1999). Hence, they must first be downscaled to a higher spatial resolution, e.g. 10’ by 10’. A useful approach to the downscaling of hydrological data is to use correction factors that are applied to the low resolution GCM output so as to preserve the statistical properties of a higher resolution observed climate dataset (Bouwer et al. 2004). A powerful dataset for carrying out this statistical downscaling is the TS2.0 database of the Climate Research Unit (New et al. 2002), which provides mean monthly global climatology (precipitation and temperature) for the period 1961–90 at a resolution of 50 km x 50 km.

Land use data: Land use is of great importance in the hydrological cycle, particularly through its effects on evapotranspiration. Hence, a map showing simplified land use categories (e.g., forest, agriculture, irrigated agriculture, urban, wetlands, water bodies) is required by STREAM. For this purpose the Global Land Cover Characteristics Database of the USGS is available at a resolution of 1 km by 1 km.

Soil water-holding capacity: A map showing the water-holding capacity (WHC) of the soil is used by STREAM in the calculation of evapotranspiration, direct runoff, groundwater seepage, and baseflow. A WHC map is available at a resolution of 2’ by 2’ from the National Resources Conservation Service or the Food and Agriculture Organization soil map at a resolution of 5’ by 5’.

Digital Elevation Model (DEM): A DEM is required to route runoff through the catchment and to simulate differences in slope steepness. For this purpose the TerrainBase DEM of the National Geophysical Data Center can be used, which has a resolution of 5’by 5’. Alternatively, the SRTM DEM is available with a resolution of 1” by 1”.

The main outputs of the model are values of discharge per time-step (e.g., monthly) for each cell on the raster grid. Furthermore, maps showing the runoff and evapotranspiration for each grid-cell can be produced, as well as summaries of relative changes in basin-wide soil moisture and groundwater.

The methods just described examine changes in the supply of water due to changes in climate. However, the availability of fresh water is also influenced to a great extent by changes in demand. For example, population growth and economic development are expected to lead to an increased demand for water in agriculture, industry, and household uses. The changes in demand that will occur as a direct result of climatic change (for example, warming may lead to more demand for water in irrigation) need to be considered when estimating water availability. Such estimates should be based on knowledge and projections available within the case study countries. It is important to note that changes in demand due to socioeconomic changes external to climate change (e.g., population increase) should not be taken into account since they are expected to occur regardless of climate change.

The changes discussed may also lead to changes in the frequency of extreme discharge events (i.e., high flows and low flows). Furthermore, an increase in the frequency of high-flow events may lead to a higher incidence of flooding, although this is also dependent on the ability of water management systems to cope with such increases. In terms of flood risk (defined as likelihood of damage associated with flooding), a number of studies in the industrialized countries suggest that this is much more sensitive to changes in land use (and hence land value) than changes in climate (e.g., Wind et al. 1999). However, analyses in the developing world are currently lacking. It is likely that the area affected by drought will increase in response to reduced (seasonal) water availability in some areas. For example, a single-model study of global drought frequency suggests that the percentage of land experiencing extreme drought at any one time, the frequency of extreme droughts, and mean drought duration will increase 10- to 30-fold, 2-fold, and 6-fold, respectively, by the 2090s under SRES's most liberal scenario, A2 (Burke et al. 2006).

Expert Judgment

Sophisticated models are available to simulate changes in water quality at the basin scale. However, the amount of high-quality and high-resolution input data required to run these models on a large scale makes them difficult to apply to large basins and at the country scale. A more robust approach to the water quality issue is to rely on expert judgments of how the expected changes in climate (temperature, precipitation) and hydrology (changes in discharge, soil moisture, etc.) will affect water quality. This should be carried out by experts in the case study countries and will provide qualitative assessments in potential changes in water quality.

Annex 3: Social

The EACC study will assist decision makers in developing countries to integrate adaptation measures into their development plans and budgets. In order to achieve this objective, the EACC study will draw on micro-level analysis to inform calculations of global costs of adaptation in all developing countries, thus complementing the top-down aggregated perspective of the cost of adaptation for an economy.

This Annex identifies the data collection needs for the social analysis of vulnerability and adaptation options as part of the EACC study. It presents the methods that will be used for data collection and later analysis. This methodology draws upon a range of analytical frameworks, including the sustainable livelihoods framework, assets and capabilities frameworks, institutional risk pooling approaches, social risk management framework, and environmental entitlements analysis. This methodological approach is intended to bridge the gap between community needs and priorities at the micro level and policy processes at the macro level, emphasizing the need for higher-level policy development and planning to be informed by lessons learned and insights gained at the local level. By identifying and assessing the most urgent adaptation needs of the most vulnerable as well as their local coping and adaptive strategies, the proposed intersectoral, bottom-up approach will provide recommendations for setting priorities for actions and help develop a robust, integrated approach for increasing resilience to climate risks at the national and local level (particularly among women and poor communities with a lower capacity to adapt).

Rationale

This approach aims to complement the existing EACC study by providing a methodology distinguished in the following ways:

- *A focus on the local level.* Because most adaptation is ultimately local, an understanding of local costs and benefits is necessary to help inform macro-level efforts to increase local adaptive capacity by channeling investments where they are most needed.
- *A focus on vulnerable and disadvantaged socioeconomic groups.* Poor, natural resource–dependent rural communities and households as well as urban populations affected by extreme weather events will bear a disproportionate burden from the adverse impacts of climate change. The most vulnerable groups are likely to be those overwhelmingly dependent on a single or a narrow range of climate-sensitive livelihood sources rather than those who are able to pool risk across several livelihood sources, including some that are significantly less climate-sensitive. Assessing the local-level costs and benefits of adaptation responses is essential to understand how better to support the adaptive capacity of the most disadvantaged groups, including women, indigenous people, and the poorest.

- *A focus on engaging vulnerable groups in collaborative analysis of what adaptation means in particular contexts and for distinct groups of people.* Emphasis is placed on joint, participatory analysis, learning lessons from past experience while acknowledging limits to this experience in the face of possibly unprecedented climate changes and seeking to engage those most directly concerned in discussion of what may be plausible means of adapting to these likely future trends as well as the pros and cons of alternative adaptation options.
- *A focus on building on existing adaptive responses.* Understanding the costs and benefits of existing adaptation practices can help scale up or multiply existing adaptation responses that have a high benefit-cost ratio and improve other adaptation practices where benefit-cost ratios are low. Effective adaptation pathways are likely to be those that progressively reduce the degree of dependence on climate-sensitive livelihood sources (e.g., through activities to enhance value chains through marketing or other improvements so as to increase market access and the share of value retained by the producer).
- *A focus on soft as well as hard adaptation options*. Even rough comparative estimates of technological and infrastructure-oriented adaptation options versus institutional and educational or skills-based adaptation options are currently missing from efforts to understand how costly adaptation to climate change is likely to be. The proposed methodology will undertake a preliminary examination of hard and soft adaptation options in specific agroecological environments and with respect to specific climate hazards.
- *A focus on ground-truthing analysis provided by the sectoral analyses.* Rapid assessment techniques will be used to elicit information on vulnerability to climate hazards as well as to take stock of corresponding adaptive strategies used by poor and vulnerable groups to confront climate change and variability. This bottom-up approach is valuable insofar that it serves to inform technical and policy experts in their priority setting for planned adaptation interventions.
- *A focus on triangulation between different data sources.* As different types and sources of data will be used to generate details and explanations about vulnerability, climate risks, and adaptation strategies adopted by the poor, the social component allows for validation of data through the triangulation and cross-checking of assumptions reached through the livelihood profiling, key informant interviews, and quantitative data sources. Consultations are a method through which the researcher may supplement available statistics used for economic modeling with local-level qualitative data, thereby helping to improve the detailed costing of individual adaptation measures. Similarly, triangulation may also be done using matrix ranking and scoring techniques where qualitative data are ranked and scored together with more household-level quantitative data.

Objectives

The social component aims to provide client countries with a methodology for identifying robust adaptation strategies and options at the local level; to provide a basis for understanding how to structure adaptation interventions so as to benefit the most vulnerable households and communities within vulnerable regions; to assess the impact of socioeconomic status, gender, and poverty in shaping a range of types of vulnerability of different social groups to climate change; and to inform perceived cost-benefit estimates for alternative adaptation responses in different agroecological zones.

Research Process

The research process will be divided into four phases:

- Data review and identification of hotspots and vulnerability/livelihood profiles based on key vulnerabilities
- Identification of alternative, robust adaptation pathways using participatory methods to elicit plausible scenarios
- Social analysis of alternative adaptation strategies
- Analysis of social implications of interventions identified by computable general equilibrium (CGE) modeling.

Data Review and Identification of Hotspots and Vulnerability/livelihood Profiles Based on Key Vulnerabilities

Identification of geographic "hotspots" particularly vulnerable to the impacts of climate change will inform the construction of a set of vulnerability/livelihood profiles for each case study country. Hotspots will be selected based on information that combines projected climate change in the country with social vulnerability data. Specifically, identification of hotspots will be based on: (a) a review of secondary and primary literature, including National Adaptation Programs of Action (NAPAs), and local knowledge, triangulated where possible with sectoral-level mapping by sector specialists for sectors covered by country cases (e.g., inundation zones for coastal management sector and extreme events in Bangladesh); and (b) poverty assessment and mapping work under way or completed.[17] The results of this analysis will inform the construction of vulnerability/livelihood profiles that will help identify common features in the way different social groups in rural or urban settings are expected to respond to climate variability and change.

The identification of hotspots will facilitate the shaping of priorities in specific locations for specific research and adaptation activities. Livelihood groups are defined as subsets of a population with fairly similar access to capital or assets that engage in similar activities required to make a living. It follows that these groups will reflect different types of vulnerability to trends, shocks, and seasonality. Invariably, there will be a need for disaggregation of groups identified by gender, age, ethnicity, and the like.

The aim is to identify hotspots and study livelihood systems within these, establishing a set of some 6–10 hotspots. Within each hotspot, two communities or sites would likely be selected. Within these, stylized vulnerability/livelihood profiles would be described, representing a socially diasaggregated range of types of vulnerability to climate variability and change. It is expected that natural resource–dependent occupational

[17] In some countries, rural hotspots may be equivalent to main agroecological zones, particularly those typically identified by client government and donors as vulnerable to climate change and variability.

groups, such as farmers and fisherfolk, will often form key livelihood groups in these areas. Two communities or sites per hotspot will be covered by qualitative field investigation. The case study teams should endeavor to have a mix of rural and urban sites across the country, and may also consider aligning site selection in part with pilot/focus districts or other zones specified in country NAPAs, where feasible.

Data collection strategies for Phase I include:

- *Review of existing qualitative and quantitative secondary data on poverty, vulnerability, and climate hazards and validation at field level (see below).* This involves a review of household surveys, participatory poverty assessments and other existing data on poverty, climate, and agroecological features. This review will help to identify geographical "hotspots" particularly vulnerable to the impacts of climate change. Within each hotspot, a nested sampling approach will be adopted to allow the construction of a set of socially disaggregated vulnerability/livelihood profiles. For example, two natural communities may be selected in each hotspot. Using wealth/well-being ranking techniques, a stratified sample of households across all well-being tiers will be identified within each community, with purposive sampling to ensure coverage of the relevant livelihood groups. Focus group discussions should be held with women, young adults, and the elderly to allow due consideration of their different experiences of climate-related vulnerability and their assessments of autonomous and planned adaptation investments to date locally, along with other key emphases such as infrastructure, household risk, and safety net provision, where offered.

- *Review of policy and institutional environment for local adaptation.* This consists of an analysis of *de jure* and *de facto* factors of the macro-level policy environment for local adaptive responses (such as land tenure and local governance, including formal and informal/ traditional governance forms). NAPA strategy documents should also be collected. Brief reference should also be made to relevant national policy emphases in agriculture, water, and the sectors selected for each country case study, as well as overall strategic development emphases of the country (with regard to commercial agriculture development, land reform, urbanization, non-farm employment, or the like).

- *Expert interviews* in each country to collect data from key informants. These can be drawn from civil society, the private sector, and research institutions.

- *Validation of livelihood profiles at field level through community/civil society focus group discussions and other participatory methods* in each community to gather information regarding climate hazards, impacts, and adaptation practices. Three to four focus group discussions will be organized in each community. The focus groups should be differentiated by gender, age, ethnicity, etc. Aside from focus group discussions and wealth ranking, site investigations may also draw upon such participatory rural appraisal tools as matrix ranking of livelihood options according to community-generated criteria (compiled by men's and women's focus groups), broad trend analysis (natural resource depletion, migration), seasonal calendars (rainfall, seasonality of food (in)security, health or illness, production, debt), and impact diagrams of observed climate trends and extreme events (household level shocks, community and area-level impacts).[18]

- *Semi-structured interviews* (10 per community site, purposively sampled from different well-being tiers during wealth ranking and female heads of households, disabled, village heads, etc.) to elicit household-level data on assets, sources of livelihood income and exchange, capital investments, credit, education, illness, access to common property resources, and other variables related to household livelihoods and shocks.[19]

- *Institutional stakeholder interviews* with officeholders in local organizations, local/ provincial government offices (e.g. de-concentrated line ministries), and other decision-making bodies at local level to gather relevant information about institutional capacities, functions, and social and institutional capital perceptions about policy and capacity.

Consultations should lead to the assessment of how benefits of interventions are shared among groups within society and, in turn, should inform the political economy of the policy reform processes leading to, complicating, or hindering the adoption of certain adaptation measures.

A first report will summarize the findings of Phase I, including the typology of vulnerability/livelihood profiles for selected hotspots (agroecological zones and climate hazards), disaggregated by gender, age, ethnicity, disability,[20] and the typology and examples of adaptive responses (e.g., mobility/migration, risk pooling, storage, livelihood diversification (including non-farm development),[21] and market exchange).

Identification of Alternative, Robust Adaptation Pathways Using Participatory Methods to Elicit Plausible Scenarios

Workshops focused on participatory scenario development (PSD) will be conducted in order to help characterize various adaptation pathways possible for different livelihood groups, given their identified vulnerabilities and assets and prevailing conditions of uncertainty. The workshops will be based on scientifically robust and socially plausible data derived from Steps 1–2 of the general EACC methodology (down-scaled climate scenarios over different time scales, and mapping of expected temperature, rainfall, drought, floods, storm surge, sea level rise, malaria-endemic zones, and other such

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[18] Reporting of results can include construction of a matrix of "conflict and cooperation" (in terms of natural resources, tenure, product markets, labor, environmental positive externalities or re-use, etc.) comparing and contrasting the interaction of different occupational/livelihood groups in the same spatial locale.

[19] Outside of these semi-structured interviews, in-country consultants and Bank country teams will also determine what panel data exist that may have relevant data for use in EACC microeconomic modeling.

[20] Investigations should also explore implications of possibly interlinked factors such as ethnicity and occupation, or ethnicity and spatial location/social settlement.

[21] This includes both individuals entering new and those adding additional sectors to their livelihood profile and/or changing the relative composition or emphasis on monetized and non-monetized livelihood elements within the overall "basket."

general and sector-specific projections as they become available). Participants will include representatives of vulnerable livelihood groups, which may include both local experts and community members or representatives. Different assumptions on which each adaptation scenario rests will be made explicit (e.g., distribution of costs and benefits among social groups). The aim is to identify the social cost-benefit of the individual activities that characterize the adaptation scenarios, bearing in mind that each adaptation pathway may have different distributional implications, even if overall costs are not very different. Box 3.1 provides examples of areas of interest to be addressed by local representatives in these workshops.

In an effort to build local capacity, facilitators will be trained before the participatory scenario development workshops take place so that future adaptation planning efforts that use such workshop approaches may benefit from the existence of skilled local facilitators.

Box 3.1: Examples of Areas of Interest for Local Workshops

Examples of sample questions to be addressed in the workshop include but are not limited to:

- What is the local vision of the future, in terms of development priorities, perceived climate change impacts, and feasible response strategies?
- Which areas/sectors are viewed to be most vulnerable? What are the key drivers contributing to that vulnerability?
- What are the specific adaptation practices used by households and communities located in different socioeconomic and ecological contexts to respond to different climate hazards?
    - Which of these adaptation responses worked, which did not, and why?
    - What are the necessary conditions required for effective adaptation to occur (e.g., interdepartmental cooperation, treatment of ancillary benefits, perceptual changes, policy priorities)?
    - What policy and operational recommendations can be derived on the basis of answers to the foregoing question?

The output of these workshops will serve to take stock of plausible future adaptation pathways for different livelihood groups and areas and highlight the distinct distributional implications of such activities. Incorporation of these issues ensures consideration of a local perspective, which may serve as a valuable guide for the planning and priority-setting process carried out by technical and policy experts who may have a more system-wide perspective.

Social analysis of alternative adaptation strategies

The findings of the workshops focused on participatory scenario development, along with results from Focus Group Discussions and community investigations for development of the livelihood profiles, will be communicated to the sector specialists in each country case study for integration into their analyses. Through joint analysis and the use of matrix ranking and scoring, local consultants will be able to make recommendations on incorporating adaptation options into the sector analyses. In addition, an economist from the EACC team and one or more sector specialist may participate in each PSD workshop and/or select community investigations.

Analysis of Social Implications of Interventions Identified by CGE Modeling
As a final step of the general EACC methodology, the CGE modeling will account for the system-wide effects of the pursuit of certain planned adaptation interventions. The social analysis will interpret which social groups will benefit and which may lose from the planned adaptation strategies recommended by the CGE models. It will recommend policies to address the groups at a disadvantage.

For example, certain activities (i.e., the provision of social safety nets or the promotion of livelihood diversification efforts) that traditionally fall within the realm of "regular" development investments may be highlighted at this stage as necessary activities that will complement the identified planned adaptation strategies. As a result, a shift in emphasis or timeframe may occur as these activities that may have "fallen through the cracks" during the macro-sectoral analysis are brought to light by the social analysis.

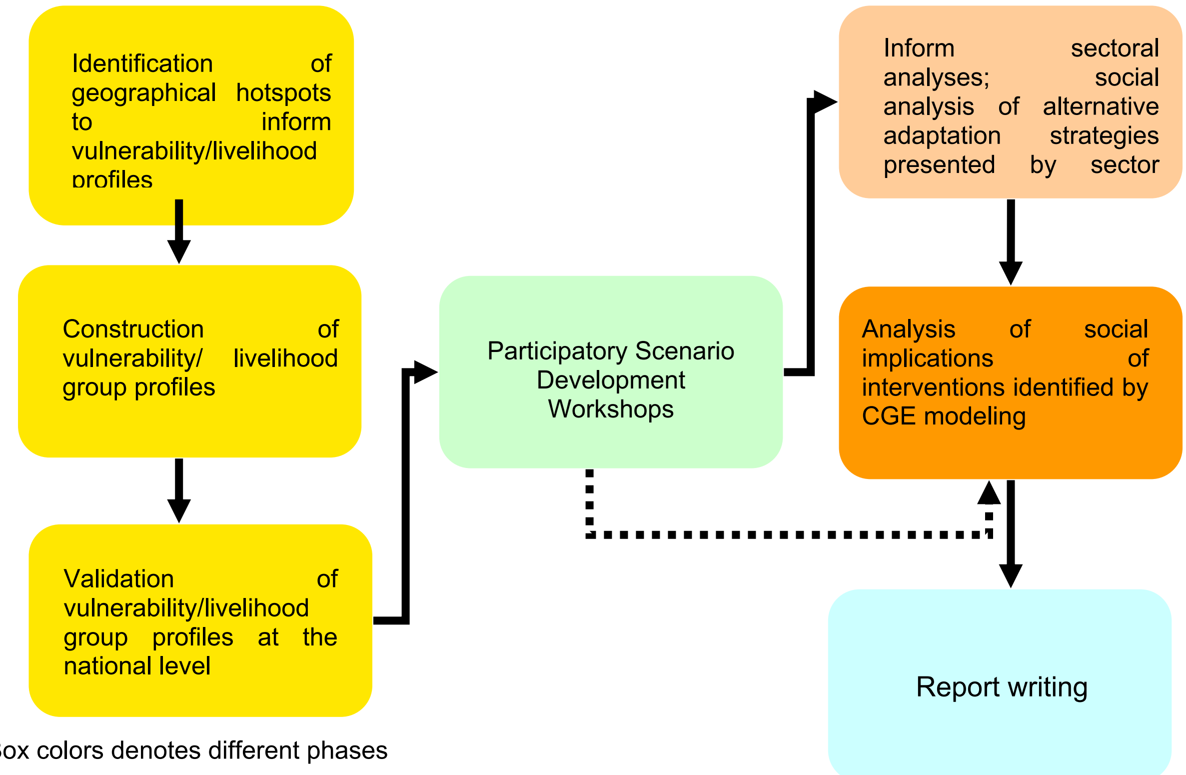
Timeline

See Table 3.1.

Table 3.1: Research Outline

	Sequence of Events	Methods	Deliverable	Timeline
Phase 1	Identification of geographic hotspots vulnerable to climate hazards to inform vulnerability/livelihood profiles	Based on secondary data and key informant/ local expert interviews	First report summarizing review of secondary data to inform livelihood profiling	January 2009
	Construction of vulnerability/livelihood profiles within communities		Preparation of information to inform second report	February
	Validation of vulnerability/livelihood profiles at local and national levels	Two communities selected in each hotspot, disaggregated by gender, age, ethnicity, etc. Based on key informant interviews with civil society, private sector and research institutions and focus group discussions with local experts	Second report detailing a) Typology of hotspots b) Typology of social and livelihood groups vulnerable to climate impacts and livelihood/vulnerability profiles for the hotspots c) Typology and examples of adaptive responses (e.g., mobility, pooling, storage, diversification, market exchange, etc.)	
Phase 2	Training of trainers Workshops focused on participatory scenario development	Local facilitators will be trained to conduct PSD workshops. Facilitated workshops held with representatives of those in vulnerable livelihood settings (e.g., community members, NGO representatives, and local experts). Groups are asked to come up with a set of storylines and corresponding adaptation activities based on given climate scenarios and preliminary options emerging from initial sectoral analyses.	The outputs of the workshops will feed into the work of the sectoral analyses under each overall EACC country study.	March
Phase 3	Social analysis of alternative adaptation strategies	Sectoral discussions on implications of PSD workshops results	Collaboration with the sector consultants in order to ensure incorporation of the social and sectoral analyses.	April
Phase 4	Analysis of distributional/social implications of interventions identified by CGE modeling	Groups that will benefit or lose from the planned adaptation strategies recommended by the CGE models will be identified. The social analysis will recommend policies to address the groups at a disadvantage.	Input into the final report	July
Phase 5	Summary reporting	Report writing	Summary report for integration into EACC report	May-July

Links between phases of the social methodology



*Box colors denotes different phases

Annex 4: Computable General Equilibrium Model

In the analysis thus far, the prices of all goods, both inputs and outputs, have been kept constant. This assumption can be justified in project-level and possibly sector-level analysis but not in an analysis of the whole economy, which is the case needed when assessing economy-wide adaptation costs. Implementation of the set of adaptation measures, such as those identified in the previous step of the methodology, is expected to lead to changes in the demand for various inputs, such as labor, land, and capital. Such changes in demand could well translate into changes in the prices of these inputs and other goods in the economy and thereby to changes in the estimates of adaptation costs. Similarly, climate change impact assessments when considered at the economy-wide level need to account for changes in factor demand and supply that could affect market prices. These constitute the "indirect effects" of climate change. Such effects also need to be accounted for to develop consistent estimates of impacts and adaptation costs at the national level.

The first, and critical, step in such a national assessment requires the linking of the "bottom-up" approach used to select adaptation measures with the "top-down" models used for economy-wide assessments, such as computable general equilibrium (CGE) models. This link basically involves incorporating agent behavior and sector-level information obtained at the microeconomic level into a CGE model. This model would, in turn, simulate three sets of scenarios: the first, which corresponds to a "no climate change" situation, would project the path of economic development characterized by a set of input and output prices; the second set of scenarios would allow for climate change impacts without planned adaptation; and the third set would allow for both impacts and adaptation measures. The last two scenarios will allow an assessment of the magnitude of the indirect effects. In addition, using a recursive dynamic CGE model characterized by myopic agents, they will allow the calculation of the transition path from the initial equilibrium to the new equilibrium.

Linking Top-down Models with Bottom-up Approach

The CGE model is today widely used to perform economy-wide policy assessments. The model allows a representation of consumer and producer behavior and the determination of market-clearing prices that equate consumer demand with producer supply. Consumers demand final goods produced by the various sectors to maximize their utility subject to a budget constraint, determined, in turn, by the remuneration received for factors of production. Producers demand inputs and intermediate goods and produce output to maximize profits. Input and output supply and demand are equated to give a set of market-clearing input and output prices that along with consumer and producer characteristics allow for the estimation of consumer welfare. Although CGE models remain at an aggregated level, they are particularly well suited for policy analysis as they link markets into a single system and allow for feedback and flow-through effects induced by policy changes. So, for example, the structure of a CGE model allows for autonomous adaptation under which agents can choose to reallocate inputs across sectors to maximize profits and utility. Sector-level analysis, by definition, does not allow for such reallocations.

Sector-specific, bottom-up models, on the other hand, provide a detailed representation of the production systems of a sector, including characteristics of producers, characteristics of production technologies, detailed descriptions of intermediate demands, distribution processes, and vectors of final goods. These models, however, neglect interactions with the rest of the economy and, in particular, the impact on market prices.

These two approaches need to be linked to develop consistent estimates of impacts and adaptation costs at the national-level. This in turn will be done by:

- *Sectoral Representation:* One of the first requirements in linking bottom-up and top-down models is to ensure that there is a consistent mapping of sectors from the bottom-up approach into sectors represented in the CGE model, as well as a realistic spatial representation of land. Note that a sector is represented in the CGE model using a single production function or as a set of subsectors with multiple nested production functions. While the former will only allow for inter-sectoral endogenous adaptation, the latter will also allow for intra-sectoral endogenous adaptation. The nature of sectoral representation will depend on the bottom-up analysis and in particular on the availability of data.

- *Incorporation of Climate Damages and Adaptation Measures:* In this step, sector-level climate damage estimates will be used to re-parameterize sector-level production functions (to be used for projections with climate change but without planned adaptation). Similarly, sector-level adaptation measures will be used to re-parameterize production functions and to account for adaptation costs. Redefining production functions to allow for climate impacts and adaptation costs and benefits is not a trivial exercise. This requires translating information from bottom-up models that is available at a highly disaggregate level into components of CGE models that are, by definition, more aggregated. One approach is to understand how climate change events will affect the supply of inputs and their productivity. So, for example, in the agriculture sector impacts from changes in temperature are incorporated into the CGE model by allowing for changes in the productivity of land and changes in its supply.

- *Distributional Impacts:* Finally, information obtained from livelihood profiles is used to disaggregate consumer demands and household asset profiles for different groups, as opposed to standard CGE models that treat consumers as a single-representative agent.

Assessment of Indirect Effects

The link between the bottom-up and top-down approaches allows an assessment of the magnitude of the indirect effects of climate change. This is done by first calibrating the CGE model to project a growth path without climate change impacts or adaptation measures. It corresponds approximately to the current climate defined by the year 2000 constant concentrations projections and includes therefore future development that would have happened in the absence of climate change.

The next step is to project the growth path allowing for climate change impacts and autonomous adaptation but not planned adaptation. As noted, this is done by re-parameterizing the production functions at the sector level to account for climate change–induced damages. Solving for the new equilibrium will give a new set of market-clearing prices and new estimate for consumer welfare, which is expected to be lower than the welfare estimates under business-as-usual (due to the overall negative expected effects from climate change in most developing countries).

The final step to assess the indirect effects of adaptation measures requires the simulation of economic growth paths allowing for climate change impacts and planned adaptation measures. This, in turn, also requires the re-parameterization of the production functions to reflect lower damages than would be the case without planned adaptation (in other words, the benefits of planned adaptation) and to incorporate adaptation costs. The exact method used to incorporate adaptation costs will depend on the information available about the cost structure of given adaption measures. If costs are available by input categories, then additional demands for inputs will be introduced to account for these adaptation costs. If, on the other hand, cost information is not broken down by input, then only uniform additional demands for inputs will be introduced. A new equilibrium is then found, giving a new set of prices and a new estimate for consumer welfare.

As long as the indirect effects are not substantial, the expectation is that the estimate for consumer welfare accounting for planned adaptation is *higher* than the consumer welfare without planned adaptation. This implies that adaptation costs, even accounting for changes in prices due to indirect effects, are lower than benefits of adaptation (or avoided damages). On the other hand, if the estimate for consumer welfare accounting for planned adaptation is *lower* than that without planned adaptation, this would suggest that the indirect effects add substantial additional costs to the adaptation costs estimated in the previous steps and cause adaptation benefits to be lower than adaptation costs. In this case the set of adaptation measures chosen in Step 4 need to be re-selected, possibly selecting measures that will not increase the demand for factors whose prices are found to increase substantially in the CGE model.

Annex 5: Generalization

Any estimate of the cost of adaptation to climate change for all developing countries based on detailed findings from six country case studies is prone to large errors. The approach used to develop these estimates, however, can narrow the range of uncertainty. There are four steps in the generalization.

The capacity to generalize rests on the ability to identify the specific factors that influence adaptation costs in the case study countries and to extrapolate costs to other developing countries based on these factors. Costs can be determined separately for people, land, or assets and aggregated in a manner that avoids double counting.

The starting point is to developing a typology for classifying population, land, or assets that are expected to have similar costs of adaptation based on the determinants of these costs. These determinants include climate-related risks (increased temperature, floods, droughts), sensitivity (coastal areas, agricultural areas, slope), and vulnerability of the population (per capita income, institutional capacity). Typically, the classification will be at the sectoral (e.g., agriculture) or sub-sectoral (e.g., agroecological zone) level, but when needed, classifications may also be cross-sectoral (e.g., cyclone activity near coastline).

The second step is to map the detailed adaptation cost estimates developed in the national studies to each of the vulnerability classes defined in the first step. These cost estimates can be supplemented with data available in the literature and from other studies when needed. They will also be explicitly parameterized to make them transferable to other developing countries, if feasible.

The third step in the generalization is to map out all developing countries based on the vulnerability class typology developed in the first step. This will result in a set of maps, with one for each of the vulnerability classes.

The final step in estimating adaptation cost for all developing countries is to apply the parameterized cost estimates for each vulnerability class to the respective vulnerability class in all developing countries.

The following two examples illustrate how the generalization can be achieved in agriculture and health.

Agriculture

For agricultural areas, farming systems, as identified in the FAO/World Bank publication *Farming Systems and Poverty*, can be used to develop land based vulnerability areas (Dixon et al. 2001). This study classified farming systems in the developing world based on the following criteria:

- *Available natural resources base*, including water, land, grazing areas, and forest; climate, of which altitude is one important determinant; landscape, including slope; farm size, tenure, and organization; and
- *Dominant pattern of farm activities and household livelihoods*, including field crops, livestock, trees, aquaculture, hunting and gathering, processing, and off-farm activities, and taking into account the main technologies used, which determine the intensity of production and integration of crops, livestock, and other activities.

For the regions Sub-Saharan Africa, East Asia and the Pacific, South Asia, and Latin America and the Caribbean, the farming systems study identified 50 distinct farm systems. Of these, 30 are represented by our case study countries. Our country study coverage of developing-country farming systems is illustrated in Table 5.1.

Table 5.1: Coverage of the FAO-World Bank Farming System Approach

Region	Number of Farming Systems in FAO/World Bank Study	Number of Farming Systems represented in case study countries	Percent of land represented	Percent of population represented
Sub Saharan Africa	15	13	93	90
East Asia and the Pacific	11	4	46	74
South Asia	11	4	33	59
Latin America and the Caribbean	13	9	74	67

For purposes of extrapolation, adaptation projects will be classified as fixed or variable cost projects. The costs of optimally selected fixed costs projects will be extrapolated to farming systems in countries outside the case studies based on average fixed cost per farming system in the country case study projects. Variable costs projects, on the other hand, will be extrapolated based on the average cost per unit area of the corresponding farming systems in the country case studies.

Human Health

Adaptation costs related to avoiding adverse human health outcomes will be determined separately for each risk factor based on the exposed population and the sensitivity of the exposed population. In the case of vector-borne disease such as malaria, for instance, global maps of the shift in vectors in response to changes in climate and the innate population characteristics will be used to classify the population into vulnerability classes globally. The per person or per area unit cost of adaptation will be estimated in the case study countries. These estimates will be supplemented with cost estimates from the literature, when necessary. The global cost estimates for each health outcome will be developed by applying the unit cost for each vulnerability class to the respective population classes.

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