Chapter 17. Economics of Adaptation

Coordinating Lead Authors
Myuyeye Chambwera (Zimbabwe), Geoffrey Heal (USA)

Lead Authors
Carolina Dubeux (Brazil), Stéphane Hallegate (France), Liza Leclerc (Canada), Anil Markandya (Spain), Bruce McCarl (USA), Reinhard Mechler (Austria), James Neumann (USA)

Review Editors
Eduardo Calvo (Peru), Ana Iglesias (Spain), Stale Navrud (Norway)

Contributing Authors
Patrice Dumas (France), Samuel Fankhauser (UK), Alistair Hunt (UK), Howard Kunreuther (USA), Richard Tol (UK), Paul Watkiss (UK), Richard Woodward (USA), David Zilberman (USA)

Volunteer Chapter Scientist
Terrence Kairiza (Zimbabwe)

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Executive Summary

Economics offers several types of insights into the following aspects of adaptation policy analysis *(high confidence)*:

- The monetary dimension of costs and benefits [17.2.1]
- The assessment of non-market costs and benefits [17.2.1, 17.3.10]

- Estimation of the distributional and equity consequences of adaptation and its impact on poverty [17.2.1, 17.2.7, 17.3.10]
- The types of adaptation investments that will occur without centralized actions (autonomous or private adaptation) and those that require centralized support or direct public action (planned or public adaptation) [17.2.1, 17.3.1]
- Approaches to the design of incentive systems that will encourage private adaptation [17.5]
- Situations where adaptation actions may totally or partially worsen climate change effects. [17.5.1]
- The impact of different "value systems" and ethical considerations on which adaptation options appear desirable [xxxx]
- Although the theoretical basis for economic evaluation of adaptation options is clear, there has to date been little experience of practical application of this approach to adaptation problems. There is however extensive experience of applying the appropriate economic frameworks in other contexts.

Economics provides important inputs to the evaluation and ranking of adaptation options in the face of uncertainty, and the result is always based on a set of preferences and world views (*high confidence*). Approximate approaches are often necessary because of the lack of data or because of uncertainties about how climate will change or how efficient adaptation actions will be. A range of economic tools helps to address these uncertainties. They can help design policies that are acceptable with a range of preferences and that are robust to existing uncertainties. There are methodologies that are able to capture non-monetary effects and distributional impacts, and to reflect ethical considerations. The resulting ranking depends on the "value system", i.e. on the weights that are attributed to different objectives and success criteria. For instance, economic decision-making based on aggregated impacts will be blind to distributional effects – and attribute a low weight to impacts on the poor – while using a Rawlsian criterion will take into account only the impacts on the poorest. Not all published economic analyses are explicit on the underlying set of preferences and values that explain results. [17.2.6.1, 17.3.8, 17.3.9]

In the presence of limited resources and differential preferences and views, adaptation implies trade-offs between alternative policy goals *(high confidence)*. Economics offers insights into these trade-offs and into the wider consequences of adaptation actions due to externalities and fallacies of composition. It also helps to explain the differences between adaptation potentials and adaptation achievement as a function of costs, barriers, behavioral biases, and resources available. Economic studies show that adaptation actions are not uniformly desirable but that their desirability depends on particular circumstances. [17.3.3, 17.3.4, 17.3.5]

Defining the benefit and cost of adaptation is difficult, limited by data, and depends on value judgments *(high confidence)*. Estimating them poses methodological, practical and moral difficulties, with consequences for how adaptation can be funded. **[**17.3.10, 17.3.11**,** 17.6]

Development and adaptation can be complementary or competitive and development can yield adaptation co-benefits, provided it takes into account climate change in its design. Adaptation actions can provide significant positive ancillary benefits such as alleviating poverty and enhancing development *(high confidence)*. Many aspects of economic development help adaptation to a changing climate, such as better education and health, and there are adaptation strategies that can yield welfare benefits even in the event of a constant climate, such as more efficient use of water and more robust crop varieties. **Maximizing these synergies requires a close integration of adaptation actions within existing policies, such as economic and development policies, an approach referred to as "mainstreaming" (*medium confidence*). [**17.2.1, 17.2.7, 17.4]

Economic analysis of adaptation is broadening in purpose and nature from an emphasis on efficiency to a more in depth consideration of inequities, non-market goods and services, behavioral biases, barriers and constraints, the consideration of ancillary benefits and costs, as well as decision-making processes including the notion of risk management (***medium confidence***). Impacts of climate change and of adaptation responses on the distribution of income and wealth, and on ecosystems and the goods and services that they provide, are increasingly recognized as important components of the overall picture that must be included in economic evaluations. The tools for such evaluations have been greatly improved in the last decade. [17.3.8, 17.3.9, 17.3.10, 17.3.11, 17.4]

Existing incentives will lead to private adaptation actions. But public action to support adaptation is justified by spill-over effects of adaptation measures, by the public goods nature of knowledge and much infrastructure, by market failures and imperfections, by the distributional impacts of climate change, and by behavioral biases. Public actions will include many instruments of different natures. Economic instruments have high potential in fostering adaptation as they directly and indirectly provide incentives for anticipating and reducing impacts (*high confidence*). Instruments comprise risk sharing and transfer mechanisms (insurance), loans including public private finance partnerships, payment for environmental services, improved resource pricing (water markets), charges and subsidies including land taxes, direct investment (especially in infrastructure and knowledge production and dissemination), norms and regulations, behavioral approaches and institutional innovations. Yet, apart from risk sharing and risk transfer instruments, the linkages to adaptation are not well understood, implementation is pending and evidence limited. Also, ill-designed economic instruments and divergences between public and private goals can create inappropriate incentives that lead to maladaptation, i.e. to an increase of vulnerability. [17.4, 17.5]

Risk financing mechanisms at local, national, regional, and global scales may contribute to increasing resilience to climate extremes (*medium confidence*). Applicable mechanisms comprise informal and traditional risk sharing mechanisms, such as relying on kinship networks, as well as market-based instruments including microinsurance, insurance, reinsurance, and national, regional, and global risk pools. Risk may be ceded by households, farmers, business and governments. With considerable disaster insurance market failure, public private partnerships are the norm rather than the exception with the public sector acting as regulator, provider or insurer of last resort (*high confidence*). The uptake of formal risk financing mechanisms is highly unequally distributed across regions and hazards Risk financing mechanisms contribute to disaster risk reduction and climate change adaptation as resources for financing relief, recovery of livelihoods, and reconstruction directly reduce the financial impact of events, and indirectly the attendant knowledge and price signals can provide incentives for reducing risk. Under certain conditions, however, such mechanisms can provide disincentives for reducing disaster risk. [17.3.8, 17.3.9, 17.4]

Current estimates of the costs of adaptation range from $48 billion to $171 billion per year globally, and from $28 billion to $67 billion for developing countries (*low confidence*), useful mostly for informing the mobilization of adaptation funds at the global level. These estimates could be higher if sectors such as ecosystems, tourism are included, and the adaptation deficits of developing countries are taken into account. The global figures are based on only a few lines of evidence [17.6.1], and cover a selected number of sectors. Focus on single sectors show that costs could be as high as $51 billion in capital and $7.2 in maintenance for energy in one country [*17.6.3.3]* or $12 billion annually for water globally. [*17.6.3.7*]. There is no consistency in the methods, time frames, purposes and coverage of existing analyses [17.6.2] with global analyses focusing on generating global adaptation prize tags and local analyses on efficiency based on cost-benefit analyses at project levels. Studies have covered sectors such as transport, agriculture and forestry, energy, sea level rise, health, urbanism, water, ecosystems, tourism and recreation, natural disaster risks [17.6.3] but these either cover selected regions or countries or only go as far as estimating the costs of impacts. Agriculture and sea level rise have the best coverage in cost estimates, covering both developed and developing countries. While there are few *ex poste* costing studies, costs for sectors such as agriculture can be reliably estimated from existing agricultural strategies that can be used for adapting to climate change. [17.6.3.2] The treatment of public and private costs of adaptation is not uniform across all studies such as in health where personal costs are omitted from costs of adaptation. [17.6.3.5] The moral basis for evaluating certain costs, such as in health and non-market impacts in urban areas are not fully addressed. [17.6.3.5, 17.6.3.6]

17.1. Background

We begin by setting out how economists view the problem of adaptation to a changing climate, presenting the basic conceptual framework for assessing costs and benefits of adaptation and then consider the scale of adaptation measures and their costs and benefits plus limits to adaptive actions.

Then we set the problem of adaptation in a decision-theoretic framework followed by an analysis how the inevitable uncertainties affect the decision-making framework. Finally we cover the ancillary effects of adaptation measures – many adaptation measures may be beneficial even in the absence of climate change –and review empirical evidence on adaptation costs.

17.2. Adaptation as an Economic Problem

People and institutions considering adaptation to climate change will generally face a wide range of possible adaptation strategies. When considering any particular adaptation strategy, one needs to judge whether the benefits of using that strategy outweigh the implementation and usage costs. The benefits and costs need to be broadly defined, taking into account resource, social, environmental and economic items (as elaborated below). The benefits, costs and resource usages are not only current but also extend into the future, possibly far into the future. Considering the uncertainty about future climate change and its impacts (e.g., on ecosystems), risks need to be considered (via through risk-based analysis or robust decision-making methodologies). More generally when there are important non-economic goals, decision-makers may need to decide what alternative can be employed to reach given set of goals at the highest net benefit or lowest net cost.

17.2.1. Forms of Adaptation Decisions and an Economic Distinction between Them

Earlier chapters have introduced the distinction between autonomous and planned adaptation. From an economic perspective this is not a very good distinction as many autonomous adaptations will in fact be planned, but there is a closely related distinction that *is* important. In particular we will continue to use the autonomous term but switch the planned term to public. Autonomous adaptations are those that will be undertaken by private parties in their own best interest (and most of them will certainly be planned – which is why we abandon that term). There are also adaptations that will be put in place by society as a whole whether this be by governments, NGOs, international organizations etc.: these we will refer to as public adaptation. This distinction between the autonomous and public adaptations corresponds to the classical economic distinction between private and public goods. Public goods are generally those that are provided by government (local or central) or another agency acting on behalf of a group of people (Samuelson). Public goods generally are non-rival in consumption (if one member of a group benefits from them then all do) and non-excludable (in that someone who does not pay for them cannot be prevented from benefiting from them). These characteristics imply that market forces will under-provide public goods, creating the need for public action (Samuelson). Some adaptation measures are private goods (such as the provision of home air conditioning in reaction to higher temperatures) and some are public goods (such as sea wall construction that protects everyone in a community or development of climate adapted crop varieties). Autonomous adaptation is largely the provision of private adaptation measures, whereas planned adaptation is the set of public adaptation measures. More generally the public ones are those that merit provision at a level above that of private adaptations. Other reasons for public provision of certain adaptation measures include the existence of:

- Divergence between the social and private discount rates where for example individuals may operate with a shorter time horizon and larger discount rate than the government
- Greater values that society places on resolving inequities caused by climate change where for example the government may wish to facilitate adaptation for disadvantaged groups or society as a whole may wish to promote adaptation in disadvantaged countries
- Motivations to resolve externalities where adaptation might reduce flooding frequency, air pollution or some other concern
- Possibilities for maladaptation where actions on behalf of one party worsen the adaptation status of other parties (for example structural flood protection in one place may worsen floods elsewhere)
- Differences in risk aversion and risk perception between society and private individuals where the government may be more concerned about protection against future climate change risks than are private individuals
- Local barriers to adaptation where human or financial capital availability may be preventing adoption of beneficial adaptation strategies

- Social concerns over threats to GDP, employment etc. where the government may act to reduce such pecuniary externalities
- Differences in information availability regarding adaptation choices. For example cropping systems from other regions may be more suitable adaptations than traditional production systems, but the region may have no experience with or information on such cropping systems
- Land ownership or property rights patterns that preclude private adaptation efforts due to local public lands, absentee ownership or areas subject to multiple private claims
- A desire to facilitate adaptation in unmanaged areas that would not otherwise respond to the pace of climate change.

Many of these points are elaborated on below.

17.2.1.1. Broad Categorization of Adaptation Strategies

There are a large number of possible adaptation actions. These include:

- Direct capital investments in facilities
- Technology development
- Investment in infrastructure to accommodate changed demands or capabilities brought on by climate change (roads, processing facilities, export facilities)
- Dissemination of information (through an extension service or other communication vehicle)
- Creation of publicly accessible information on how to employ a particular adaptation alternative
- Human capital enhancement (investment in education)
- Redesign of or development of new adaptation coping institutions
- Changes in norms and regulations to facilitate autonomous actions.

Not all adaptation involves investment or is costly. Some adaptation actions will be costless or low cost although non-cash costs are also relevant and may be significant. For instance, behavioral changes can play a role in the adaptation process (e.g., changes in the organization of the work day or in crop planting times). Also, some adaptation measures involve modification of recurring expenditures as opposed to investments. Additionally changes in institutions and organization structure may make them able to include responses to climate change in their normal operations. Also depreciation of existing capital mandates its replacement over time and adaptation in the form of adopting new technology may occur during normal replacement without additional cost. Finally, low cost modifications in ex-post response capacity for disaster relief may facilitate adaptation (e.g., strengthening of emergency services).

17.2.1.2. Broad Definition of Benefits and Costs

It is generally not appropriate to treat the consequences of adaptation decisions in purely monetary terms. Beyond standard economic accounting of costs and revenues decisions can affect:

- Income distribution and poverty
- Welfare of both current and future generations
- Regional distributions of economic activity, including employment
- Non-monetary factors (e.g., altered water quality, habitat implications, human health, and quality of life, impacts on ecosystems).

Generally adaptation measures need to be evaluated in terms of multiple metrics representing factors such as those above in addition to conventional economic measures of costs and benefits. Material in the section below on co-benefits and in Chapter 2 of this volume elaborates.

In terms of economic costs and benefits climate change will have direct and indirect impacts, and adaptation actions can aim at reducing direct and indirect impacts (as elaborated in Hallegatte et al., 2011). Direct impacts refer to the impacts that changes in climate will have on productivity, installed productive capital, and amenities that affect the welfare function. Indirect impacts refer to the total impact of climate change on welfare, including the impact of a) macroeconomic effects (see, e.g., Fankhauser and Tol, 1995); b) general equilibrium issues and cross-sector interactions (Kemfert, 2002; Bosello et al., 2007); c) diversion of funds and the crowding out effect on other investments (Hallegatte et al., 2007) and d) technical progress (Hallegatte and Dumas, 2008). Some adaptation actions can aim at reducing indirect impacts. For instance, if urbanized areas cannot be protected against more intense storms, the welfare effect of more disaster losses can be lowered by insurance and disaster relief funds.

17.2.2. Toward a Realistic Assessment of Strategy Attractiveness

Adaptation that overcomes all climate change damages is almost certainly not achievable. Given the wide variety of potential adaptation options, some will not be chosen. There are a number of reasons for these statements. The most straightforward is that while there may be options that would in principle yield a high degree of adaptation, they may cost (from now on when we use the words cost and benefit we mean the broad definition of these words as explained above) much more than the benefits that would be obtained from implementing them.

Social and political limitations, resource competition and other factors limit the potential for strategy adoption and perfect adaptation. In particular, there are a number of factors that limit adaptation and also make it unlikely that perfect adaptation will be achieved. A conceptual way of looking at this for a given adaptation endeavor is in Figure 17-1.

[INSERT FIGURE 17-1 HERE
Figure 17-1: The narrowing of adaptation from suggested adaptations to what will be done. Forces causing the narrowing are listed in black.]

Figure 17-1 shows that while there is a wide spectrum of adaptation choices, practical considerations will make using all of these and the complete offsetting of climate change impacts impossible in the real world. There are several reasons for this: First, the laws of physics suggest it is impossible to cancel all impacts (e.g., it will be impossible to restore outdoor comfort in places where temperatures get very high). Second, certain ecological and other natural processes (extinction, melting of glaciers) may be irreversible, making it impossible to restore earlier conditions. Third, resource availability and insufficient knowledge will reduce our ability to undertake all adaptation possibilities. Fourth, some adaptation measures may not be consistent with other objectives being pursued and this may rule these options out. Fifth, implementation barriers, obstacles, financial constraints and other market failures may make it impossible to implement otherwise desirable adaptation options.

17.2.2.1. Adaptation as an Investment

One would expect that the returns to increasing levels of adaptation investment will be decreasing. As argued in Parry et al (2009), initial benefits from adaptation can be achieved with relatively low levels of effort but as the amount of adaptation increases the costs of implementation gets successively more expensive.

17.2.2.2. Adaptation as a Dynamic Issue

Adaptation is not a one time action, aimed at going from a stable situation to a new one that is different but stable as well. On the contrary, societies will have to continually adjust to a changing climate for centuries to come (IPCC, AR5, WG1). The challenge is therefore to continually adapt life styles and economic systems to a "perpetually changing" climate (Hallegatte, 2009). To address this challenge, it is important to consider adaptation as a basically long-term transitory and transitional process.

Adaptation investments will often have persistent results. Consider the construction of seawalls, or the identification of genes leading to drought resistant crop varieties. An appraisal of the desirability of a particular adaptation strategy must consider the timing of investments versus the timing of benefits. This again brings up the general rubric of investment analysis, as virtually all investments require upfront expenditures and benefits that arise over time. Also alternative adaptation policies may have differing dynamic impacts. For example protecting now can lead to more investment in protected areas, which in turn may raise vulnerability in the future as climate change proceeds (Hallegate, 2011). This could happen with a sea wall or flood insurance.

17.2.2.3. Project-Based Adaptation

The emergence of adaptation funds and the likelihood that substantial adaptation will be based on proposed adaptation projects raises complex issues. Funds may be allocated by examining a number of competing adaptation strategy proposals and deciding upon "winners". Much as in the language in the Kyoto Protocol regarding mitigation possibilities, there are some conceptual issues that merit consideration.

The first of these are the linked concepts of baseline and additionality. Namely, just as in the Kyoto Protocol mitigation context, it is desirable to fund adaptation strategies that would not have occurred in the absence of that funding (those that would not be autonomously or privately adopted). This implies the need for additionality tests that check whether an alternative needs to be supported given the possibility of autonomous investment.

A related concept involves adaptation strategies that pursue actions that are beneficial even in the absence of climate change. When considering a project with both adaptation and other benefits, it is natural to inquire what fraction of total cost should receive adaptation support, and what fraction should be financed by other funding sources. Among various possibilities, adaptation funding could finance only the incremental cost attributable to adaptation, i.e. the additional cost required for adaptation to climate change. As an alternative scenario, the adaptation of existing infrastructure might involve upgrades and thus an incremental cost. These projects would be pure adaptation projects and be funded at 100%.

Some countries have adaptation strategies that are used at below optimal levels under the current climate (they have an adaptation deficit- Burton, 2004), which would also be useful in adapting to future climate change. In that case one has to choose whether to fund the correction of the existing deficit as well as additional adaptation needs. For example irrigation investment may be beneficial under current conditions and even more so under additional climate change. Funding only the additional needs may be efficient from a strict adaptation to the future viewpoint, but to the extent that valuable currently-needed projects are not undertaken this can be inefficient.

Another important concept is that of leakage. Adaptation investments may augment or reduce commodity production, in turn changing market prices and potentially negatively affecting adaptation decisions elsewhere. This is explored in a mitigation context by Murray, McCarl and Lee (XXXX) and many others (see the reviews in an indirect land use case by Hertel et al (2010) or a carbon leakage case by McKinley et al (2011) or Smith et al (2007)). A test for whether leakage is significant is whether there is any diversion of goods from traditional markets because of the adaptation. For example, an adaptation that manufactures wetlands on existing croplands should consider the leakage elsewhere because the cropland commodity production has been reduced and could be replaced elsewhere.

There is also a need to deal with performance uncertainty in the considering the effectiveness of adaptation strategies: claims about the effectiveness of future adaptation to climate change are subject to substantial uncertainty (i.e. for exactly how long a sea wall would provide protection or whether a crop variety will perform as anticipated). It may be worthwhile placing a lower confidence interval on adaptation potential. See Kim and McCarl (2009) for further development of this concept in a mitigation setting.

Finally there is the concept of permanence where one needs to consider the duration of the adaptation investment and not assume that the result persists forever.

17.2.2.4. Burden Sharing

The existence of adaptation funds certainly raises the dual issues on the donor side of: Who funds adaptation? How much? Similarly on the recipient side: Who should receive adaptation investment assistance? How much? For what? There is certainly an uneven distribution of costs of climate change and this does not match up with the distribution of emissions so there may be some need for compensating transfer payments to overcome losses. There has been work on this regarding general considerations of liability and ethics; political issues, polluters pay principles and North-South issues.

17.2.3. Adaptation and Mitigation as Competitive or Complementary Investments

AR4 WGII chapter 18 presents a discussion of trade-offs and synergies between adaptation, mitigation and climate change damages. Often these are rival choices where investments in one might preclude investments in another, whether it be an alternative adaptation or mitigation strategy. There is also rivalry with consumption and traditional production-enhancing investment where large adaptation or mitigation investment programs preclude consumption and productivity enhancing-investments. Additionally there is resource competition where mitigation and adaptation may well act on the same lever or employ the same resource (e.g., infrastructure, or available land) and also compete with traditional production. For example some adaptation strategies require land-use change as do some mitigation strategies, and land is of course in limited supply, and in addition that land can also be used for traditional production of food, fiber and ecological goods. This implies a portfolio approach is needed considering the overall returns across all ways of using available funds. (See de Bruin et al (XXXX) or Wang and McCarl, 2012)

Adaptation and mitigation are complementary in the long run. Because mitigation reduces the uncertainty and magnitude of future changes in climate, it makes adaptation cheaper, and thus more efficient (Hallegatte et al., 2010).

Also, some adaptation policies have mitigation co-benefits, such as a better building insulation that reduces air condition needs in summer, but also heating needs in winter. On the other hand, some adaptation policies have mitigation co-costs, such as the generalization of air conditioning or seawater desalinization.

17.2.4. Inter-Relationships between Adaptation Costs and Residual Damage

In the climate change context, residual damages are those damages of that remain after adaptation actions are taken. Some literature has attempted to define residual damages more definitively. The U.S. National Academy of Sciences, for example, distinguishes potential impacts (defined as, “All impacts that may occur given a projected change in climate, without considering adaptation”) from residual damages (defined as, “The impacts of climate change that would occur after adaptation”) (U.S. National Academy of Science 2010). Others have simply identified residual damages as those that remain after adaptation is implemented (World Bank 2010).

Straightforward examples can be developed in the context of responding to sea-level rise. Absent adaptation, sea-level rise is expected to lead to such effects as permanent inundation of some coastal property, accelerated erosion of beaches, more extensive damage from storm surges, human migration, loss of coastal wetlands, and increased intrusion of salt water to coastal freshwater aquifers. A multitude of adaptation options exist for responding to most of these impacts – most often considered are seawalls, beach nourishment, and planned retreat of human settlements. Seawalls do nothing to reduce saltwater intrusion. The saltwater intrusion impact would therefore be a residual impact after adaptation via sea walls. In addition, seawalls may hasten the loss of wetlands resources (see USGCRP 2009). In the case of an adaptation action itself leading to an adverse impact, the definition of a residual impact is less clear – is the loss of wetlands attendant to construction of seawalls a residual impact, or an additional, non-monetized cost of adaptation?

_____ START BOX 17-1 HERE _____

Box 17-1. Disaster Risk Reduction, Adaptation, and Residual Risks

The residual risk from disasters related to climate change will depend upon how much adaptation is carried out. Risk-based adaptation analyses provide comparisons of the impacts of sea level rise (in absence of adaptation) and the cost of adaptation under various amplitudes of sea level rise. This is shown in Hallegatte *et al*.'s (2011) analysis for the city of Copenhagen as portrayed in ure 17-2, which shows the mean annual losses due to storm surges, as a function of the level of protection (as represented in cm of installed protection), for the current sea level and with 50 cm of sea level rise.

Assuming that the city is homogenously protected by dikes at 180 cm above current mean sea level, the vertical arrow shows the cost of 50 cm of SLR, which is the increase in mean annual losses due to a 50 cm SLR in absence of adaptation (i.e. with no change in the 180 cm protection level). The horizontal arrow shows the need for adaptation, i.e. by how much the protection level should be increased to maintain unchanged mean annual losses. Using dike cost estimates, this need for adaptation can be translated into adaptation costs.

Figure 17-2, therefore, shows both the cost of SLR in absence of adaptation, and the cost of adaptation to cancel the SLR impacts. These cases are two specific options, but other possibilities exist: for instance, one can decide to upgrade protection so that current annual mean losses are reduced (i.e. reduce a current adaptation deficit).

[INSERT FIGURE 17-2 HERE
Figure 17-2. Illustrative example assuming a homogenous protection at 180 cm above current mean sea level (in the ‘No SLR’ and ‘50 cm SLR’ cases). The vertical arrow shows the cost of SLR in the absence of adaptation. The horizontal arrow shows the need for adaptation to maintain unchanged mean annual losses.]

Source: Hallegatte *et al*. (2011)

_____ END BOX 17-1 HERE _____

17.2.5 Defining What Constitutes The Cost of Adaptation

Not all studies define the costs of adaptation in the same way. Some literature defines the cost of adaptation as simply an additional investment cost to accommodate adaptations under future climate change (McCarl, 2007 or more generally the UNFCCC study). A full accounting for the costs of adaptation needs to consider capital, operating, and nonmonetary costs of adaptation, considering metrics beyond those in monetary units. An economic approach would consider at least some of the constraints noted above, and would likely take one of two definitions: 1) Costs of adaptation are the full range of costs incurred to undertake all appropriate adaptation measures; or 2) Following classical economic concepts of compensation, costs of adaptation are the full range of costs incurred to restore economic welfare to pre-climate change levels (World Bank 2010 following classical economic literature on compensation levels). In terms of individual projects this would include the costs of fully implementing a given set of adaptation strategies including the opportunity cost of the funds used.

A further issue in defining the cost of adaptation is isolating costs incurred to adapt to climate change from costs that might be incurred for other purposes. This is a common problem in economic analyses, and typically involves specifying a reasonable counterfactual baseline case. If such a baseline can be developed, the costs of adaptation can, in theory, be isolated from costs of actions that would otherwise be undertaken. The task is complicated, however, by the long time frames over which climate change and adaptation will occur. For example, identifying a baseline for agriculture, with climate change, over the next forty to 100 years is a formidable task, particularly because it can be argued that the last two or more decades of history have already been affected by climate change. In addition, the presence of an adaptation or development deficit also complicates the task.

In some cases, it may be argued that the cost isolation is not important – investments ought to be evaluated using the best forecast of future conditions, including changing climate. Further, if an adaptation strategy is effective in responding to a climate challenge, such as reduced water availability for agriculture, and that same strategy is also determined to be a good investment in response to the current adaptation or development deficit, would we label that strategy as climate adaptation? And should the costs of that measure be included among the costs of adaptation, if the measure could have been justified as welfare-enhancing regardless of climate change? Many analysts continue to struggle with these questions

17.2.6. Methodological Considerations

Over the last few years, a wide range of methodologies using different metrics, modeling approaches and assumptions, and focal time periods, has been developed and applied to assess adaptation costs and benefits. As part of a recent European based survey, Watkiss and Hunt (2010) identified a number of approaches (see left column in table below) and assessed their strengths and limitations. This analysis is expanded herein to a more global coverage with some more recent additions (see Table 17-1). Note all of these methods continue to evolve, and more recent studies now use several of these approaches together.

[INSERT TABLE 17-1 HERE
Table 17-1: Methodologies for the economic assessment of climate change and adaptation.]

The methodologies serve a variety of different purposes, emphasize different temporal and spatial scales and assess adaptation to different climatic hazards (changes in means; extreme weather events, etc.). Thus, whilst the purpose of global scale IAM-based analyses is to help inform possible choices or tradeoffs in international climate change policy, impact-based assessments of adaptation serve to raise awareness of potential adaptation needs, and provide a first indication of possible adaptation financing needs to regional and national agencies. The most recent interest has been the move towards practice-based adaptation assessments and identifications, which are more concerned with identification and evaluation of national and sub-national adaptation strategies, plus their sectoral and cross-sectoral economic implications. The empirical evidence base that these applied methodologies have generated to date is relatively thin; and the lack of common assumptions in these applications further limits the scope for cross-study comparisons. The broad methodological frameworks above can employ a wide range of decision support methods for appraisal. These include traditional approaches (cost-benefit analysis, cost-effectiveness analysis and multi-criterion analysis) as well as the methods increasingly adopted for handling uncertainty (e.g. robust decision making, real option values, portfolio analysis) discussed later in this chapter.

There also are some methodological issues that merit attention.

17.2.6.1. Data Quality and Quantity

Callaway (2004) suggests that one of the major challenges in identifying the costs and benefits of adaptation is the low quality and limited extent of sector level data, especially in many developing countries. Further, he notes the importance of the informal economies and social networks in many countries, where the transactions that are part of the adjustment to climate variability and climate change are unreported.

Hughes et al (2010) discuss the difficulty in identifying the costs of adaptation for water infrastructure in OECD countries. Even in these countries, an assessment of adaptation costs was hindered by lack of historical data sets. Further, they note too that historical weather data is not sufficiently detailed to estimate climate data needed for infrastructure planning, such as 24h precipitation. There is also very little data on the costs adaptation actions, for example estimates of the costs of retrofitting an existing house for increased hurricane resistance in the US (Bjarnadottie et al. 2011) span a very broad range. These are important for identifying the costs of different adaptation measures. There is very little discussion in the literature on data gaps related to assessing the benefits of adaptation.

17.2.6.2. Costs and Benefits are Location-Specific

According to Hughes et al. (2010) different underlying growth rates between different regions may affect total costs of adaptation. They found large regional differences in adaptation costs in water services between different regions with a range going from about 13% of baseline costs for Eastern Europe to a small cost savings for North America.

Calculating distributional impacts requires detailed geographical knowledge of climate change impacts, but these are a major source of uncertainty in climate models. Compared with developed countries, there is also a limited understanding of the potential market sector impacts of climate change in developing countries.

17.2.6.3. Costs and Benefits Depend on Socio-Economics

The future level of adaptive capacity in human and natural systems will affect how well society can reduce the damages from climate change. Assessments may under- or overestimate adaptive capacity, leading to under- or overestimates of positive or negative impacts. It is sometimes assumed that climate will change but society will not (Pielke, 2007: cf. Pielke and Sarewitz, 2005; Adger et al., 2003; Lorenzoni et al., 2000).

Future predictions of development affect estimates of future climate change impacts, and in some instances, different estimates of development trends lead to a reversal from a predicted positive, to a predicted negative, impact (and *vice versa*). Some studies have examined the impact of different regional growth rates on hurricane damage and, as expected, higher growth rates present greater vulnerability because property is more exposed to hurricane damage (Bjarnadottir, 2011). On the other hand, higher incomes allow the funding of risk-reducing policies (from flood protection to more robust buildings), which reduces vulnerability.

Lucena et al. (2010), in studying impacts on the Brazilian energy sector, note that there are socioeconomic costs and benefits that are difficult to assess and measure and include direct damage caused by climate change impacts as well as the cost involved in attenuating those impacts. In a study on hurricane damage to houses in the US, the analysis focused on benefits in terms of reduced building damage to home-owners but omitted other benefits, that, although difficult to monetize (such as reduced social disruption, reduced business losses, reduced need for emergency services) would make adaptation strategies more cost effective than shown (Bjarnadottir et al., 2011; Hallegatte and Przyluski, 2011).

17.2.6.4. Discount Rates Matter

Because adaptation measures and their cost and consequences stretch far into the future, a core question is how much weight to place on future costs and benefits relative to those in the present. Opinions vary sharply on how to answer this question, leading to major debate (Baum, 2009). It is impossible to know the preferences of future generations, which affects the valuation of future costs and benefits (DeCanio, 2007:4, Beltratti Chichilnisky and Heal XXXX). Dietz et al (2007) note that a low discount rate is almost always needed for uncertain dangerous climate change in the far-off future to matter. A low discount rate is one of the primary reasons why the estimates of climate damage presented in the Stern Review are higher than in other analyses.

It is important to recognize that there are two different discount rates – the **pure rate of time preference**, and the **social discount rate**. For the type of projects considered in this chapter, the relevant rate is the social discount rate, the rate to be used in project evaluation (see Heal 2009). The value of this rate depends on the pure rate of time preference, which is now often taken to be very small - Stern takes this to be 0.1%, Heal puts it at 0, as did Ramsey (192X) in his original study of optimal economic growth – and on the value assumed for the elasticity of marginal utility. The social discount rates generally used are between 1 and 2.5, although there are no particularly good arguments for this (see Heal 2009). As Heal (2009), Guesnerie ( ) and Sterner and Persson ( ) point out, allowing a flow of environmental services to enter consumption can change the social discount rate substantially, as it is reasonable to assume that climate change will affect the flow of environmental services negatively. This can generate a negative growth rate and a low or even negative social discount rate.

Some authors have provided comprehensive sensitivity analysis of the effect of a range of value judgments (i.e. discounting, time horizon calculations) and scientific uncertainties (climate damages, baseline, climate sensitivity and abatement costs). Nordhaus chooses a value of 1.5% for the utility discount rate (which can be combined with the elasticity of marginal utility of consumption to lead to the discount rate overall as in the Ramsey equation) while Stern uses a much lower value of 0.1%. Nordhaus emphasizes the consistency with the rate of return on investment as a driving rationale while Stern points to ethical issues. Heal (2009) notes that the pure rate of time preference, being a value judgment, cannot be derived from observational data: he describes Nordhaus's argument as deriving an "ought" from an "is," a categorical error in philosophy.

Weitzman (2001, 2007) treats the discount rate as random and points out that we should in this case average different discount factors instead of discount rates. Wen (in: Bjarnadottir et al (2011)) investigates the sensitivity of optimal design against multi-hazards to discount rates varying from 0% to 9%. He proposes using a discount rate that decreases over time, which is also that used by the Green Book of the UK Treasury for long-term appraisals (from Hof et al, 2010).

17.2.7. Adaptation, Poverty, Equity, and Development

There is, in some cases, a relationship between actions taken to improve adaptive capacity and actions taken to enhance economic development, particularly in lesser-developed countries. Development goals can be consistent with adaption goals, but adaptation and development goals will not always align. Depending on the context, economic development goals may focus on improving education, public health, infrastructure, agricultural productivity, technology, or governance, among others. Many of these priorities could be enhanced thorough adaptation actions. For example, road construction practices might be altered to accommodate higher temperatures and more intense rainfall (World Bank 2009); agricultural investments might increase heat tolerance or drought resilience (Butt et al. 2005, Strzepek et al. 2010); and public health investments might be oriented toward increasing resistance to climate-enhanced diseases (Tol and Dowlatabadi 2001; Samet 2009). It is also the case that development in general will make more resources available for adaptations such as flood protection and infrastructure strengthening.

A relevant question therefore concerns whether economic development should be considered a form of adaptation. SREX shows extreme event damages are largest in developing areas. If it is reasonable to assume that development would diminish vulnerability and raise autonomous adaptation capability and as such it may be an attractive adaptation strategy (Schelling 1992, Schelling 1997, Tol 2005). Very little research has yet been conducted to resolve this question, although efforts have begun. Models that include dynamic effects suggest that reductions in economic output and diversions of capital to defend again climate impacts through adaptation could have larger implications for economic growth over time than the direct effects of climate change (Fankhauser and Tol 2005) [also cite World Bank EACC country studies here?].

There certainly will be tradeoffs between economic development and adaptation due to scarcity of financial resources (Tol 2005, Fankhauser and Tol 2005). Broad generalizations on the relationship between growth and climate adaptation should be avoided, however, because the limits to growth vary substantially in each country as does the degree to which growth and adaptation goals overlap. There is a lack of detailed regional, bottom-up analyses of the effects of adaptation in the short- and long-term, coupled with top-down analyses that take better account of the effect of economic dynamics such as capital accumulation and how those dynamics are affected by climate, adaptation, and economic development policies.

The IPCC Special Report on extreme events, disaster risk management and adaptation shows that sustainable development is an international goal that can be threatened in some areas by climate change, thus climate change adaptation is a component long-term sustainability (Wilbanks and Kates, 2010). Discussions of relationships between sustainable development and climate change appear in (Cohen et al., 1998; Yohe et al., 2007; Davis, 2001; Garg et al., 2009; Bizikova et al. 2010).

17.3. Decision-Making and Economic Context for Adaptation

This section will focus on making decisions about adaptation activities, the actors who might implement them, their interactions with and expectations of other actors, and on the limits and obstacles to efficient adaptation. Existing assessments have shown that the impacts of adaptation may eventually be very different depending on whether or not adaptation is carried out in a first-best setting (e.g., with perfect information and anticipation). Examples include building and urbanism (Hallegatte et al., 2007), coastal zone management (Yohe et al. 1995, 1996, 2011; Hallegatte et al. 2011; West et al., 2001), agriculture and water. This section reviews the analysis of more realistic decision-making on adaptation, and the limits to optimal adaptation.

17.3.1. Linking the Adaptation Decisions of Different Actors

When one economic agent defines its own adaptation strategy, it needs to take into account what other agents will be doing. An attractive policy can be made inefficient because of actions by other actors (e.g., providing higher-cost heat-resistant accommodations for tourists who then decide to spend their time in a different location which has also been improved). Other actions can become attractive only because other actors adapt (e.g., reducing water demand at a manufacturing plant can be profitable because of an increase in farmers' water demand for irrigation).

One special case of such interactions between adaptation actions is the case of public adaptation plans (e.g., national adaptation plans or local adaptation plans) and private adaptation actions. Public plans, indeed, need to account for the action of other economic agents – and their reaction to both climate change and the public adaptation plan. Earlier chapters and sections have introduced the distinction between private (or autonomous or spontaneous) adaptation – which is the adaptation that private economic actors will undertake – and public (sometimes called planned) adaptation – which is what public actors will do.

As noted in section 17.2.1, public goods are those that have to be provided by a government (local or central) or by some other agency that acts on behalf of a group of people. Public adaptation needs to take into account the responses of private actors, including their positive and negative consequences.

Taking the example of the adaptation of a coastal region to sea level rise, the local firms and households will undertake adaptation actions ranging from small actions (e.g., buying sand bags to prepare against coastal floods) to more radical ones (e.g., moving away from the region). A public plan needs to take into account and to facilitate these spontaneous actions. If the public plan is based on hard protection, for instance, firms and households may decide to invest even more in the protected area, increasing vulnerability in case the protection fails or is overtopped (Hallegatte, 2011). The public plan needs thus to account for these reactions in its design. Sometimes a public plan is more about coordinating private actor responses than about direct public actions. If the most cost-efficient solution is a strategic retreat from the coastal zone (e.g., because protection is impossible or unaffordable), then the plan needs to ensure a coordinated retreat, by providing appropriate incentives, compensations, and possibly strict regulations.

17.3.2. What are the Objectives of Adaptation?

The first problem met in the design of an adaptation strategy is the definition of its objective. Adaptation is a response to climate change, but its objectives can be diverse depending on which actor is to adapt, and on world-views and beliefs. On one hand, the objective of adaptation may be to cancel all impacts (negative and positive) of climate change and maintaining the status quo ante. Another possible objective is to cancel adverse impacts and capture all positive opportunities, so that the welfare gain (or loss) from climate change is maximized (or minimized). This is the IPCC (2007) definition of adaptation. But these general objectives can be translated in many ways into operational rules and indicators for success.

Cancelling all impacts of climate change is likely to be impossible, for reasons linked to irreversibility, technical limits and ultimately the law of physics (e.g., it will be impossible to restore outdoor comfort where temperatures get very high). But doing so would anyway be undesirable, as the cost would undoubtedly exceed the benefits. For instance, it might be possible to continue growing the same crop in spite of temperature increase but it would require additional investments in irrigation infrastructure that are more costly than shifting to another crop. Certainly today crop and livestock mixes are shifting (Seo et al)

Part of the literature presents adaptation as a continuous, adaptive, flexible process, based on learning and adjustments. This branch emphasizes the need for change to preserve welfare in spite of climate change, and opposes the static view of adaptation as aiming to maintain a status quo (literature from SREX Chp 8). Consistently, many adaptation projects emphasize the role of learning, experimenting, and using reversible and adjustable strategies (Berkhout *et al.*, 2006; Pelling *et al.*, 2007; Leary et al., 2008; McGray et al., 2007; Hallegatte, 2009; Hallegatte et al., 2011c).

Adapting to climate change will imply trade-offs with other policy goals such as economic development and poverty reduction (Barnett and O'Neill, 2010; Beckman, 2011; Bigio and Hallegatte, 2011; Viguie and Hallegatte, 2011; Owour et al., 2011; Ericksen et al., 2011), mitigation policy objectives and other environmental goals (Wilbanks and Sathaye, 2007; Wilbanks, 2010; Hallegatte, 2009; Yohe and Leichenko, 2010; Bizikova *et al.*, 2010), or among scales of action (from communities and cities to regions and states, see Wilbanks, 2007, Corfee-Morlot et al., 2011).

Using the example of sea level rise and a coastal zones, different actors may disagree on what adaptation means: some may support emigration or inland migration as an adaptation solution, while others may claim that adaptation means making it possible to continue living in the region. And even if the objective is agreed, different values and beliefs will lead to different assessments of what is the "best" strategy. More risk-averse individuals may find it unacceptable to live behind seawalls that may fail, while others may find it the best option. Public adaptation plans may lead to large redistribution, for instance because flood zoning affects land values by making pricy sea-view plots worthless.

But even when the objective of adaptation is agreed upon, and when an indicator for success can be consensually defined, the design of an adaptation strategy will meet a series of problems linked to market failure and behavioral biases as identified below.

17.3.3. Information, Transaction Costs, and Market Barriers

A transaction cost is a cost incurred in making an economic exchange (Coase, Williamson). Transaction costs include the cost of accessing markets, the cost of accessing information, and the cost of reaching an agreement among economic parties. Transaction costs also include enforcement costs, to make sure parties respect contracts. Because of transaction costs, a mutually beneficial exchange may be impossible. Some adaptation actions may be impeded by transaction costs. These concepts are relevant for the adaptation issue.

For instance, information on climate change and its impacts and on adaptation options is not available today in sufficient quantities, particularly in developing countries (citation World Bank WDR 2010?). This creates situations of asymmetrical information that may lead, on the one hand, to failure to adapt where this is possible and beneficial, and on the other it may hinder efficient market operation, creating location advantages and producing new inequalities (between and within countries). As for other transaction costs, public authorities and the international community have an important role to play in this case in the production of information (fundamental research, R&D) and in the dissemination of this information between countries and to households, firms and local communities within countries (citation on information dissemination).

Because of transaction costs, some publicly beneficial adaptation measures may not be privately beneficial. For instance, it may not be profitable enough for a homeowner to insulate his when transaction costs are accounted for, whereas the collective benefit is considerable if a large number of homeowners all do this (Hallegatte et al., 2007). This type of sub-optimality has been referred to as a “market barrier,” as they appear even in absence of market failure (Jaffe et al., 2004).

Using once more the example of sea level rise and the adaptation of coastal zones, land prices should adjust progressively and regularly in response to sea level rise, transferring the high value of coastal plots inland as the amenities from the proximity from the sea moves and the risk from floods increases in coastal plots (West et al. 2001). These changes in land prices should provide incentive for spontaneous adaptation by private actors. But in practice, imperfect information on risk levels and transaction costs in the land markets can prevent land prices from perfectly integrating risk levels and amenities, preventing land market from providing the needed incentives. This in turn may make public action necessary.

Adjustment costs are fundamentally driven by coordination failures (Hallegatte et al., 2010), and by factor immobility, i.e. friction in the capital and labor markets. There would be no adjustment costs if workers were able to move at no cost from one industry to another, firms were able to instantly modify their fixed capital and technologies, and all economic actors were coordinated by perfect information. But experience with trade liberalization shows that frictions play a key role in determining adjustment costs. First, we observe that trade liberalization creates and destroys jobs in different sectors, but causes only limited flows of labor into expanding sectors. In Brazil for example workers displaced from de-protected industries were only absorbed by sectors with comparative advantage sectors several years later (Muendler 2010). Moreover, there appears to be significant heterogeneity in the mobility of different types of workers, with lower adjustment costs for younger workers as well as for skilled workers.

17.3.4. Externalities, Agency Theory, and Market Failures

In addition to market barriers and transaction costs, adaptation may face market failures and create externalities and moral hazards. Policies have to be designed to provide the correct incentives. Some adaptation actions are not privately profitable but are socially desirable. For example, it may not be privately profitable to conserve a forest and forgo timber and land use revenue, but it may nevertheless be attractive socially because of carbon sequestration and biodiversity conservation. Along the same lines, it may be profitable for a developer to build in a flood-prone area even though this raises the future costs for the community (pressure on the healthcare system, temporary relocation of flood victims, etc.). In fact in many countries the risks of building in flood plains are assumed by the community through social insurance agencies such as FEMA in the U.S., so that there is a direct transfer of risk from the private sector to the community (reference Kunreuther).

There are also synergies and trade-offs between adaptation actions and mitigation goals (see below section 3, and also Wilbanks and Sathaye, 2007; Wilbanks, 2010; Hallegatte, 2009; Yohe and Leichenko, 2010; Bizikova *et al.*, 2010). For instance, the massive use of air-conditioning or the desalination of seawater can increase energy consumption. Again there are trade-offs and synergies with other policy goals, such as economic development, as noted above (Barnett and O’Neill, 2010; Beckman, 2011; Bigio and Hallegatte, 2011; Viguie and Hallegatte, 2011; Owour et al., 2011; Ericksen et al., 2011).

An optimal action for one stakeholder may therefore have negative external impacts on other stakeholders and not correspond to the socially optimal action, thus requiring public actions (e.g., norms and standards, tax measures or institutions) in order to avoid these effects.

Institutional arrangements may also reduce incentives. Where adaptation planning is decentralized at the local level, the community may need to provide anticipatory adaptive measures before impacts are felt. Support provided only after impacts are observed may create disincentives for anticipatory action (Burby et al., 1991). The regulated insurance schemes that have been created in many developed countries may need to be amended to maintain incentives for businesses and households to adapt to new conditions. For instance, if flood-prone areas are changing, regulations requiring special building norms in these areas will need to be changed. Also, some economic sectors are highly regulated, to the point that stakeholders may not react to climate change since they only take environmental and climatic aspects into account by complying with fixed regulations and standards. This is largely the case in the civil engineering sector, for example (citation). In such situations, we cannot expect spontaneous adaptation without additional incentives, and public action is therefore necessary for adaptation, either by modifying the standards and regulations so as to take climate change into account, or to delegate adaptation to the stakeholders by changing regulatory limits so that spontaneous adaptation becomes possible. Since standards are generally established to compensate for a lack of incentives, delegating adaptation to stakeholders can only be done by establishing adequate incentives.

Sea level rise and coastal adaptation example provides a good illustration of these issues. Even assuming that information is widely available and transaction costs nonexistent, adaptation will face additional market failures. There is first the problem of moral hazard: households, firms and local authorities do not adapt because they expect the national government (or international support in developing countries) to provide support when climate change impacts become too large. For instance, it is likely that a region that is affected by a large coastal flood will receive external support for building new protections against flood. Lack of spontaneous adaptation would thus lead to increased external support, providing a disincentive for local action. There are also moral hazard issues at the micro level, for instance when developers build housing in risky areas and sell them, without supporting the risk they have created. There are also externalities, since one households or firm located in a risky location may create higher social damages than its own private losses (for instance because of network effects, in particular, see Tierney, 1997, and Henriet et al., 2012). Retreat from coastal areas, for instance, requires coordination across many actors, from households to utilities and the managers of transport infrastructures. There is no easy way to coordinate such a move without public coordination, explaining why it is often referred to as "strategic retreat."

And even with perfect information, no transaction cost or market barriers, and public action to correct externalities and market failures, adaptation actions by economic actors may be suboptimal, because of behavioral biases.

17.3.5. Behavioral Obstacles to Adaptation

Economic agents adapt continuously to climate conditions. They adjust in an incomplete, ad hoc manner and do not always use all available information, especially long-term projections on future conditions. This has been well documented for adaptation to natural risks (Magat *et al.*, 1987; Camerer and Kunreuther, 1989; and Hogarth and Kunreuther, 1995). Also, it is observed that individuals defer choosing between ambiguous choices (Tversky and Shafir 1992; Trope and Lieberman, 2003), which is a common situation where climate change adaptation is concerned. Also, individuals value differently profits and losses, leading to systematic decision biases (Tversky and Kahnman 1974). This behavior is consistent with what is observed in other domains (Shogren and Taylor, 2008); for instance, in-depth studies show that these behavioral issues partly explain why households do not capture all profitable investments in energy efficiency (see the review in Gillingham et al., 2009).

Both private and public investment decisions do not always adequately take long and very long-term consequences into account (for public decisions, see Platt, 1999 and Michel-Kerjan, 2008; for private decisions, see Kunreuther et al. 1978, and Thaler, 1999), which could justify public intervention. Focusing on protection against frequent events may lead to greater vulnerability to larger and rarer extreme events (Burby, 2006). In the context of long-term consequences, it has been observed for energy efficiency investments that households act in a way consistent with a discount rate of 20 to 100%, which is inconsistent with other investment decisions (Train, 1985). But this is only partially due to the lower weight attributed to decision consequences occurring far in the future, especially by poor households (citation on preference for the present), and to the increasing uncertainty on remote futures. Part of the difference has been attributed to non-rational behaviors (Reeder *et al.*, 2009).). Also, the provision of basic services by public authorities is often taken for granted by private actors, whereas major changes in climate conditions could make these services impossible or too costly to provide (for example, access to water for agriculture on the long-term). Public decision-makers may want to give a large weight to the far future (in economic terms, to use a lower discount rate than private decision-makers), justifying public action.

It is likely that these behavioral aspects play an important role in risk management today, and will be a limit to adaptation (Repetto, 2008). Social norms, heuristics, “rules of thumb” are often use by many agents (e.g. on energy use, see Allcott and Mullainathan, 2010) and adapting to large changes in climate conditions will challenge these behavior rules (Tol et al. ,1998; Fankhauser et al. 1999; Batterbury, 2008). Tversky and Kahnman (1974) illustrate important decision biases when new conditions are met and decision heuristics have to be changed.

The sea level rise example also illustrates well the important of these aspects. Even in absence of all market failures or limits to access to information, individuals are found to be unable to use information on rare catastrophic events, such as a 100 year storm surge. It means that providing risk maps to individuals before they buy a home is not sufficient to assume that they make their own decision about how much risk they are ready to bear – even in absence of any indirect consequence of their risk-taking behavior on others. Specific measures targeting these behavioral biases may be necessary, including “nudging” and influencing individuals through communication and education campaign.

17.3.6. Ethics and Political Economy

A difficulty in allocating resources to adaptation is that it is not so obvious how to choose a performance indicator for adaptation measures (Fuessel?). The effects and outcomes of policies are often measured using classical economic indicators like GDP or cost benefit tests. But the limits of such indicators are well known, and have been summarized in several recent reports (e.g., CMEPSP, 2009; OECD, 2009, Heal 2012). These limits include the failure to take into account the depletion of natural resources, the welfare impacts of environmental change, and distributional issues.

Climate change impacts are also cultural (e.g., loss of historical heritage, loss of traditional livelihood) (literature) or environmental (e.g., loss of coastal wetland) (literature), and adaptation can aim at preserving these assets. The social value attributed to these assets is linked to the services they provide (literature) and to ethical considerations (literature).

Efficiency is important, but another major factor that justifies public intervention is equity. Climate change impacts vary greatly by social group, and many studies have suggested that the poorest are particularly vulnerable (e.g., Tol et al., 2004, Stern, 2006; O’Brian et al., 2004). Some individuals, firms, communities and even countries may be unable to afford adaptation measures themselves, even if these measures are in their own interest. Government (local, regional, national or international) may want to help these actors through transfer mechanisms, e.g., fiscal, or international transfers. Consideration of justice and fairness will play a role in how adaptation options are designed (Pelling and Dill, 2009; O’Brien *et al*., 2009; Dalby 2009; Brauch, 2009a, 2009b; O’Brien *et al*., 2010b).

Consequently, we must compare measures whose benefits go to very different individuals. The economist's traditional approach in this case is to argue that we have to choose the most cost-effective projects and then eventually resort to financial transfers to satisfy any equity objective (Brown and Heal Review of Economic Studies 1979: Atkinson and Stiglitz, book). However this argument depends on the economy satisfying a rather strong set of assumptions and being in a fully efficient initial state. In more realistic second-best situations the equity-efficiency dichotomy is no longer so sharp. And in practical terms there is a problem in that the transfers needed to compensate for distributional impacts are difficult to organize and may not be politically acceptable. At the international level, in particular, development aid is often politically controversial (Bulir and Hamann, 2008). So in practice governments may need to build distributional goals into their polices, as the equity-efficiency dichotomy is hard to realize.

17.3.7. Economic Decision-making with Uncertainty

17.3.7.1. Uncertainty and Portfolio Theory

Decisions about adaptation have to be made in the face of uncertainty. Future climate trends are not known with precision, and the impact of adaptation measures is also generally subject to a significant margin of error. Sources of uncertainty include:

- Uncertainty about global climate change scenarios. The extent and consequences of climate change are far from certain with IPCC (2007) projections ranging from an average temperature increase of +2°C to one of +4°C. These are the central tendencies of the projections: there is a spread of possible outcomes about each of these. It would be dangerous to plan with only one of these two scenarios today. Taking the 2°C scenario, we run the risk of putting off taking the measures necessary to deal with the impacts of a 4°C scenario until it is too late. On the other hand, focusing only on the 4°C scenario, we run the risk of overinvesting in adaptation actions and therefore wasting scarce resources. This uncertainty is a combination of socio-economic and policy uncertainty (leading to uncertainty in future GHG emissions) and a scientific uncertainty (on how the climate system will respond to GHG emissions).
- Uncertainty about how global changes will translate into impacts at the local level. For example, even for a given amount of global warming (measured as a change in global mean temperature), climate models diverge on the way in which climate change will affect the frequency and intensity of storm events in the north of Europe. Similarly, half of the climate models project an increase in precipitation in West Africa; the other half projects the opposite. Uncertainty is therefore exacerbated when we have to assess the local impacts of climate change to establish an adaptation strategy. Moreover, local climate changes are obscured by natural variability, making it particularly difficult to detect them.
- Uncertainty about the reaction of major cycles (e.g., water), ecosystems and societies to global and local climate changes. The response of ecosystems and human communities to changes in local climates is also extremely uncertain, but it influences what is an effective adaptation strategy. For example, the ability of coral reefs to cope with sea water warming, sea level rise and ocean acidification is highly uncertain, but relevant adaptation options for small islands depend strongly on this issue. Adaptation strategy design needs to include this uncertainty from the earliest stages.

Concepts from risk management and portfolio theory can provide a framework for thinking about these issues. In particular, diversification across a range of adaptation measures may be desirable to manage overall adaptation risk, as argued in AR4 chapter 18, where a diversified portfolio of adaptation and mitigation is suggested.

17.3.7.2. Comparing Adaptation Measures under Uncertainty

Next we summarize methods that allow us to compare adaptation measures within a context of uncertainty about the future climate.

The first method is cost-benefit analysis under uncertainty (Arrow et al., 1996). In this approach subjective probabilities (i.e., probabilities based on beliefs derived from scientific knowledge rather than from relative frequencies of occurrence) are attributed to different climate futures, using expert knowledge or Baysian methods (e.g., Tebaldi et al., 2005; New and Hulme, 2006). The “best” project will then be the one that maximizes the expected net present value (i.e., the average of the costs and benefits weighted by the occurrence probabilities for every possible states of the world). Risk aversion can be taken into account by seeking to maximize the expectation of a concave utility function rather than working with monetary costs and benefits. The greater the degree of concavity, the greater the degree of risk-aversion reflected in the utility function: with sufficiently risk-averse utility functions it is possible to implement an approach that focuses largely on the worst possible outcomes, the so-called “max-min” approach. The cost-benefit approach also allows one to consider basic needs and the asymmetry between profits and losses.

When relatively complete information is available, cost-benefit analysis is particularly useful because it makes it possible to evaluate policies in a wide range of possible outcomes, as well as enabling a detailed study of the differences between measures, for example, when there are different consequences in terms of time or spatial distribution of costs and benefits. Even when all of the information necessary for the calculation is not available, a sensitivity analysis often makes it possible to reveal trade-offs that are not necessarily obvious beforehand. Hallegatte (2006) provides an illustration of this method.

Application of cost-benefit analysis requires that the costs and benefits of adaptation measures can be evaluated in monetary terms. In cases where the impacts are on the availability of goods and services traded in markets this is straightforward: there are market prices available to value these items, although these prices may need to be corrected to allow for the impacts of monopoly power or for external costs not reflected in market prices (see Little and Mirrlees , Dasgupta Marglin and Sen, Squire and van der Tak).

In cases where there are no market prices for evaluating the costs and benefits of adaptation, a range of non-market approaches to valuation can be adopted. These can be applied to benefits that are public goods, or benefits that are private goods but are not marketed, as is the case with some environmental services (ecosystem services). These non-market approaches can be divided into revealed preference approaches and stated preference approaches, and are discussed in section ***17.3.10*** below.

An alternative to cost-benefit analysis when particularly disastrous outcomes are possible is the use of "risk management" methods, whose aim is to limit the probability that losses reach a critical level or that a particularly bad scenario is realized. What this means in practice is that adaptation policies are selected so that for example scenarios with losses exceeding 1% of the GDP have a cumulative occurrence probability of less than one in a thousand. The hazard threshold retained (1% of the GDP in this case) and the cumulated occurrence probability (one in a thousand here) are subjective and have to be determined through a political process.

When conducting cost-benefit analyses under uncertainty, an important concept is that of option value or quasi option value (Henry 1974, Arrow and Fisher 1974). The key point here concerns irreversible actions, such as the destruction of an ancient monument or a unique environment. Because unlike normal choices such actions can never be undone, we need to be particularly careful about carrying them out in the first place. There is an “option value” associated with conserving something that can never be replaced: by conserving it we have the option of continuing with it or not in the future, whereas we lose this option if we destroy it. The point is particularly important if we do not really know the value of the item to be conserved, and may learn more about its value in the future. A number of the impacts of climate change are irreversible, as are consequences of some adaptation policies, so that the concept of option value is relevant here. This concept has been applied to climate policies by Kolstad and XX, Fisher and Narain, and is reviewed by Heal and Kristrom (2003).

All the methods just mentioned require subjective occurrence probabilities for each climate scenario. However, it is often difficult to determine these probabilities. Climate problems are in the realm of ambiguity rather than risk, meaning that while there is some information about the relative likelihoods of different outcomes, this information does not constitute a probability density function (Gilboa 2009, 2010). There is little work that applies such ideas to climate policy (see Henry and Henry, Millner Dietz and Heal 2010 and Allen, Edenhoffer, Field, Heal, Kunreuther and Yohe 2012). One approach is to work with a range of different scientific models describing the process of climate change, each stochastic, and posit the existence of second-order subjective probabilities over these models being correct. These alternative models can be thought of as scenarios.

In practice, a set of possible scenarios is often the only available information. In this case, a scenario-by-scenario decision approach can be used (see, e.g., Lempert and Schlesinger, 2000), looking for policies that are acceptable within a maximum number of scenarios. The aim in this case is this no longer to maximize the benefits within a given scenario (or within the average of a set of scenarios) but to remain above the acceptable level of benefits for the set of scenarios (or for as many scenarios as possible).

The most rigorous version of this method, in which we try to remain above an acceptable level for all of the scenarios, is similar to what is referred to as the "maximin approach", in which we simply attempt to optimize for the most pessimistic scenario. The disadvantage of this approach is that the set of strategies is determined on the basis of the most pessimistic hypothesis that is generally highly unlikely. In a more flexible version, this approach aims at implementing measures that are sufficiently effective within all the scenarios, i.e., uncertainty-robust measures or measures that can be adjusted when new information becomes available (Groves and Lempert, 2007; Groves *et al*., 2007; Lempert and Collins, 2007; Lempert, 2007; Lempert and Collins, 2007; Dessai *et al*., 2009a; Dessai *et al*., 2009b; Hall, 2007; Fankhauser *et al*., 1999; Goodess *et al*., 2007; Hallegatte, 2009).

17.3.7.3. Uncertainty in Future Climates, Maladaption, and Adjustment Costs

The combination of uncertainty on climate change and of the long asset lifespan leads to the risk of maladaptation. Maladaptation is defined by the IPCC (2007) as "a change in natural or human systems that leads to an increase rather than a decrease in vulnerability." A distinction must be made between two sources of maladaptation. An "*avoidable*" maladaptation situation can arise from a "poor choice" *ex ante*, i.e., from the inadequate consideration of all the information available. This is the case, for example, if adaptation measures are established in view of a unique climate scenario, without including uncertainty. An "*unavoidable*" *ex post* maladaptation that resulted from an entirely appropriate decisions based on the information that was available *ex ante*.

One example of maladaptation is related to the preservation of existing economic structures. Marginal modifications can be sufficient to cope with early or limited climate change. For instance, in the agriculture sector changes in planting dates can be sufficient to cope with a small warming. Using artificial snow-making can allow low-altitude ski resort to continue operation if the temperature increase remains limited. Beach nourishment can cope with limited sea level rise. For larger changes in climate conditions, however, these marginal actions may not remain efficient, and structural changes may be necessary. Examples include switches to different crops in agricultural regions (Rosenzweig *et al*., 2004), a shift toward alternative tourist activities in ski resorts (Elsasser and Bürki, 2002), or even retreat from some coastal areas (Fankhauser, 1995). Disasters also can overwhelm coping capacities of communities and require structural changes (e.g. Blaikie *et al*., 1994; Sperling *et al*., 2008). If structural change eventually becomes necessary, investments in marginal changes may be seen as maladaptation.

A maladaptation situation *ex post* can result from entirely appropriate decisions based on the information that was available *ex ante*. As a result of the uncertainty about the impacts of climate change, the analysis *ex ante* cannot ensure the choice of policies that will be optimal *ex post*. For example, it may appear desirable today to better regulate new construction in low-lying coastal zones. However, if we realize in 2050 that the most optimistic scenario on the rise in sea levels was the right one, this adaptation measure could then appear to be unnecessary, even if it appears desirable with today's information. This type of "*unavoidable*" maladaptation cannot be avoided and can only be regretted *ex post* if all of the information available was not used *ex ante*.

The World Bank EACC study identifies limitations in handling climate uncertainty in the EACC and proposes the need to consider a larger range of scenarios, Monte Carlo simulations and other probabilistic approaches as a way of managing these uncertainties more explicitly. Monte Carlo simulation is used by a number of authors to estimate damage risk and incorporate uncertainty in changes to climate (Bjarnadottir et al (2011), Dietz et al. (2007)). Dietz et al (2007) describes the uncertainty attached to the consequences of GHG emissions as "Knightian" in that we do not know their objective probabilities – this is the concept of ambiguity referenced above in section 17.3.8.1. The usefulness of CBA as a decision support tool depends on our ability to define subjective probability distributions over relevant variables and on the accuracy of these probabilities.

One way to manage these uncertainties is to select "no-regrets" adaptation options, that is, to select those options whose benefits are delivered regardless of the direction and extent of climate change. Hallegatte (2009) suggests a number of no-regrets adaptation measures, including soft measures such as insurance and restrictive land use planning, which are useful regardless of the direction and nature of future climate changes. The benefits of these will be more robust than some irreversible measures such as building coastal defenses, which may not have any benefits in the absence of increased storm surges.

17.3.8. Examples of Multi-Metrics Decision-Making for Adaptation

The impacts of climate change can include many items that cannot readily be given monetary values. Multi-criteria analysis is applicable when such cases arise. In this approach, criteria do not need to be measured in common metrics, and can be weighted to reflect relative importance. It allows decision makers to include a full range of social, environmental, technical, and economic criteria in a balanced manner—mainly by quantifying and displaying trade-offs to be made between conflicting objectives that are difficult to compare directly. Multi-criteria analysis is also useful when there is insufficient data to conduct a cost-benefit analysis or cost-effectiveness analysis.

This approach is widely applied in the context of environmental issues, including climate change adaptation assessments. Recent examples include urban flood risk in Bangladesh (Grafakos 2011) and in Germany (Kubal et al. 2009), adaptation options for climate change in the Netherlands (De Bruin et al. 2009; Brouwer and van Ek 2004), climate change-related health risks (Ebi and Burton 2008), adaptation planning in Canada (Qin et al. 2008). Older examples include identification of vulnerability in the agricultural sector and assessment of alternative crop options (Julius and Scheraga 2000) and climate change adaptation options in Africa (Smith and Lenhart 1996). UNFCCC developed guidelines for adaptation assessment process in developing countries (the process of National Adaptation Programmes of Action, NAPA), in which it suggests the use of multi-criterion analysis for the prioritization of adaptation measures (UNFCCC 2002). In this context, (Burundi 2007) provides an example of standardized multi-criterion analysis scoring for a variety of adaptation actions.

The set of criteria used to prioritize adaptation activities depends on the study. There are several toolboxes for multi-criteria decision-making, and they give detailed outline of the considerations that need to be taken into account when identifying criteria (Janssen and Van Herwijnen 2006; Belton and Stewart 2002; Dodgson et al. 2009; Keeney and Raiffa 1993). Criteria have generally to fulfill some qualitative attributes such as value relevance, understandability, measurability, non-redundancy, independence, balancing completeness and conciseness, operationality and simplicity (Belton and Stewart 2002). Stakeholders can be involved in the definition and weighing definition of the criteria: this ensures that a wide range of perceptions is taken into account, and enhances stakeholders' involvement in the adaptation process(Brooks et al. 2009; Kiker et al. 2005).

Example of criteria are importance, urgency, no regret characteristics, co-benefits, and effects on mitigation effects of policies (used in the Netherlands, De Bruin et al. 2009); sustainable environmental management, cost, aptitude to adaptation, struggle against poverty, food security, prevention of climate risks, female empowerment, economic growth (Burundi 2007); vulnerability reduction, cost, enhancement of ecological condition, public and political acceptance, employment generation, achievement of MDG, institutional and technical capacity(Grafakos 2011); degree of adverse effects of climate change, poverty reduction, synergy with other environmental actions, cost effectiveness(UNFCCC 2002).

Multicriteria analysis also provides a way to account for distributional impacts, and avoid giving a higher weight to wealthier individuals. "When a monetary metric is used to aggregate costs and benefits across different communities, the aggregate outcome will be biased towards the consequences of climate change policy in the richest subgroup" (Downlatabadi (2007), p.655: in Baum (2009)).

17.3.9. Non-Marginal Changes

It is more complicated to evaluate the costs and benefits of significant (non-marginal) economic shifts and transitions than to assess marginal or incremental changes. In fact, two economic equilibrium states that are very different from each other can be difficult to rank economically. If tourism stops being a viable economic activity, it can be replaced by many different sectors (from manufacturing to services, for example), and it is not easy to anticipate which alternative activity is the best in terms of population welfare. Moreover, assessing the difference between two economic trajectories is often a question of measuring transition costs, not only differences between final equilibria. This is similar to the analysis of trade liberalization, which focuses on the assessment of transition costs (Francois, Jansen, and Peters, 2011).

As an example, some regions have developed their economies based on a single sector, like tourism or agriculture. In most general equilibrium models used to assess the macroeconomic cost of climate change, if a sector becomes less profitable because of climate change, resources (labor and capital) shift to other more-profitable sectors and climate change leads to a change in economic structure with no significant loss in terms of production and income. In models that assume full employment, no economic shift can lead to a surge in unemployment and a large drop in output.

17.3.10. Non-Market Costs and Benefits

As we noted above, the costs and benefits of adaptation measures will often be reflected in changes in the amounts of non-market goods and services, so that there will be no prices available for valuation. The valuation of non-market impacts is now a large and well-developed field, with a good recent overviews presented in Freemand (2003) and the National Research Council (2004). The approaches available divide into two categories, revealed preference and stated preference.

Revealed preference approaches are based on the study of actions that people take that indirectly reveal the value that they place on a non-market good or service. Asking how much extra a house is worth because it is in a clean air district allows us to assess the value that buyers place on clean air: asking how much extra a house is worth because it is near a good school allows us to evaluate the value that buyers place of access to good schools. Factoring out the value of clean air or good schools can be done by hedonic regressions.

Stated preference approaches are based on interviews with a representative sample of potentially affected individuals, who are asked to complete a carefully-structured questionnaire designed to elicit their willingness to pay for the good or service affected by the adaptation project, as reviewed in de Bekker-Grob et al. and National Research Council (2004)

17.3.11. Changes in Values and Preferences

As discussed in Section 17.2.6.4, discounting and modeling risk aversion attempt to capture resource-related preferences and values contingent on time and uncertainty. Adaptation appraisal techniques that include monetization of the costs and/or benefits of adaptation apply weights to these preferences. For the sake of consistency, however, and particularly in decision contexts that demand consideration of longer-term impacts contingent on the evolution of adaptation pathways, additional determinants of future preferences may need to be accounted for. These determinants may themselves be dependent on socio-economic conditions and so would be expected to change over time as society develops.

Layton and Brown (2000) explore this issue in the context of GHG mitigation whilst Hunt and Taylor (2009) outline methods that could be used to model changes in future preferences, and provide examples in the contexts of climate change impacts on health and cultural heritage where such modeling is likely to be valuable in making decisions relating to adaptation. Beltratti Chichilnisky and Heal consider option values that arise as a result of uncertainty about future preferences. As noted above, stated preference techniques are often applied in such non-market valuation contexts. The confidence which we can place on values derived in this way will be constrained by the extent to which future scenarios can be posed that allow the respondent to effectively construct preferences, as well as the plausibility of the scenarios themselves.

17.4. Ancillary Economic Effects of Adaptation Measures and Policies

In addition to creating an economy that is more resilient to the effects of climate change, adaptation strategies often have unintended ancillary effects of substantial importance. Specifically, environmental and economic co-benefits/costs can be generated by adaptation strategies. For example, while coastal protection can avoid loss of property and damage to humans in the face of climate change, it can also benefit society in the face of severe storms or tsunamis. At the same time, sea walls can negatively affect tourism and recreation. Another example is that the development of heat and drought resistant crop varieties can also be useful outside of the realm of climate change, increasing productivity in bad years and in marginal agricultural areas.

Ancillary effects also arise when investment funds are devoted to mitigation or non-climate related investments, as we indicate below in the section on economic evaluation of ancillary effects. For example, action to reduce CO_2 emissions from power plants, a classic case of mitigation, would simultaneously reduce emissions of oxides of nitrogen (NOx) and particulates and in turn diminish consequent pollution-induced health effects (Burtraw et. al. 2003). These reductions are likely to be positive for adaptation to a warmer world.

17.4.1. Broad Economic Consideration of Adaptation

Because of ancillary effects, strategies that enhance adaptation can be attractive not only in the case of climate change but also in more general settings. Given the uncertainty in the magnitude and timing of anthropogenically-induced shifts in climate, it is certainly beneficial to pursue "no regrets" adaptation strategies that generate substantial benefits without climate change or in the face of other evolving societal/environmental forces.

Examples of climate-related strategies that have substantial co-benefits include the following:

- Sea walls that protect against sea level rise and at the same time protect against tsunamis – and as noted above also affect the recreational value of coastal areas. However they also have co-costs causing damages to other environmental attributes such as adjacent regions, fisheries and mangroves. (Frihy, 2001);
- Crop varieties that are adapted to droughts and heat – and also raise productivity in the absence of climate change (Birthal et al, 2011);
- Better building insulation – which protects against heat also reduces HVAC energy consumption (Sartori and Hestnes, 2007) and mitigates greenhouse gas emissions;
- Public health measures targeted at insect-borne diseases whose range will expand in a warmer world – also may have health benefits at present (Egbendewe-Mondzozo et al, 2011);
- More efficient use of water –adaptation to a drier world- also benefits current conditions of water scarcity. Development of lower-cost desalination methods has the same merits (Khan et al, 2009);
- Locating infrastructure away from low-lying coastal areas –provides adaption to sea level rise and also protection against tsunamis and storm surges;
- Storm-resistant buildings improve adaptation and in cyclone-prone areas, provide better flood protection and drainage;
- Green roofs in urban areas – provide adaptation to increased heat (Niachou et al, 2001) plus lower winter heating requirements and reduce storm water runoff (EPA, 2009), but also consume water;
- Afforestation and reforestation can both mitigate by carbon sequestration and adapt by securing soil and reducing water run-off (Pattanayak et al,2005);
- Reducing the need to use coal-fired power plants though energy conserving adaptation is also a mitigation strategy which can have air quality and health impacts (Burtraw et al, 2003).

This list implies that analyses of the benefits/costs of adaptation strategies should be conducted so as to generate information under both current and non-climate-change-related evolving future conditions. We should also note that co-benefits and co-costs are context and place specific due to distinct local environmental and socioeconomic characteristics. Therefore assessments need to be made for specific situations.

17.4.2. Examples of Ancillary Benefits from Adaptation

The literature contains a wide variety of contributions identifying ancillary benefits from adaptation to climate change. Table 17-2 gives a summary of some representative contributions in this setting.

[INSERT TABLE 17-2 HERE
Table 17-2: Examples of ancillary benefits.]

17.4.3. Economic Consideration of Ancillary Effects

Consideration of ancillary effects in the climate adaptation arena has largely been discussed on a strategy by strategy and sector specific basis, addressing for example adaptation in the form of coastal protection or crop varieties. But ancillary effects also need to be considered when trading off competing alternative and can influence the socially optimal portfolio of adaptation.

To examine how the selection of a socially optimal portfolio of adaptation measures is affected by co-effects we adopt the externalities model advanced in Baumol and Oates (1975). Suppose that a country decides to adapt to climate change and formulates rules that permit a mixed portfolio of investments and has a given sum of money to be allocated between the two competing alternatives. Also suppose that funds allocated to either activity reduce damages from climate change but with diminishing returns. Adaptation funds should ideally be allocated between the two activities so that the marginal returns to each are the same.

Suppose that both strategies generate positive ancillary effects. Then the socially optimal allocation of adaptation investment will differ from the private optimum and will favor the activity with the larger ancillary effects. The key is that the degree to which consideration of the ancillary effects shifts the investment share depends on the relative magnitudes of the ancillary effects so both must be estimated. Furthermore consideration of the ancillary effects of a single strategy presents a biased view that can only be resolved by looking at the ancillary effects of all alternative strategies. In the mitigation case, Elbakidze and McCarl (2007) argue that it may be best to omit ancillary effects from consideration when deciding on investment allocation due to the complexity of complete consideration and estimates that the ancillary effects in the settings they examine are roughly of the same magnitude. Many others have argued for the inclusion of co-benefits and co-costs in the adaptation decision-making process (e.g., Grafakos 2011, Kubal et al. 2009, De Bruin et al. 2009; Brouwer and van Ek 2004, Ebi and Burton 2008; Qin et al. 2008; Viguie and Hallegatte, 2011) but comprehensive estimation of these is a large burden.

Furthermore here we have assumed a fixed budget for adaptation. But equally important, and more difficult, is how to determine how much should be spent in total on adaptation versus other climate-related and non-climate investments. The general rule, of course, is that the marginal social returns to all forms of expenditure should be the same, perhaps allowing for distributional impacts by weighting benefits and costs to different income groups differently (Brent, 1996; Musgrave and Musgrave, 1973). In practice governments try to achieve this by setting a hurdle rate of return for public expenditures: if the marginal returns in all areas are equal to this then the equality of marginal rates is assured (Atkinson and Stiglitz, 1980; Starret, 1998)

As discussed above and developed elsewhere (e.g. Baumol and Oates, 1975), the presence of ancillary effects can lead to market failure and it may be socially desirable for government policy interventions to adjust market outcomes. Theoretically, subsidies or taxes that reflect net ancillary effects could correct market failures. However, before such a policy could be implemented, we need to consider whether regulatory intervention in the form of subsidization/taxation is justified based on differences between ancillary effects.

One should also realize that ancillary effects are likely to vary across geographically distant adaptation regions that use the same strategy. For example, adaptation actions that increase resilience to drought in West Africa would probably result in different ancillary effects in North America. Thus the subsidy calculation needs to be carried out on a case by case basis.

This calculation is also complicated by the diversity and multiplicity of ancillary effects, which could include improved wildlife habitat, other biodiversity impacts, improved soil and water quality, development of recreation sites, etc. Each of these external effects is difficult and time-consuming to appraise. In such situations it is common to use benefit transfer approaches, adapting values calculated in similar studies. There are however dangers to the extensive use of benefit transfers, generally considered to be a “second-best” valuation method with devised guidelines governing their use (NRC, 2004).

Evaluation of most of these co-effects requires application of advanced estimation techniques such as non-market valuation analysis, crop production simulation, etc. (Plantinga and Wu 2003, Ribaudo 1989, Pattanayak et al. 2005, Matthews *et al*. 2002). In addition, adaptation activities could result in diverse ancillary effects on biodiversity, soil and water characteristics, among other things, which are difficult to compare in terms of monetary values.

In order for subsidization/taxation to be economically justifiable the magnitude of the benefits gained from subsidization need to exceed the government expenditures plus transaction costs of implementation (McCann and Easter, 2000, Stavins 1995).

17.4.4. Adaptation and Development Pathways

Adaptation is often considered as a specific set of actions aimed at reducing climate change negative impacts and maximizing climate change benefits. In this “stand-alone” framework, adaptation actions are additional policies, and they do not affect other policies, such as development or economic policy. This is for instance the approach followed by the “National Adaptation Plans for Action” of the UNFCCC (2002), which is based on standalone projects that target identified vulnerabilities.

Another vision of adaptation is considering adaptation as an additional objective of development, which influence development policies (Klein et al. 2005; Füssel, 2007; Kok and De Coninck, 2007; O’Brien et al., 2012). This approach is often referred to as a “mainstreaming” of adaptation in public policies, in which all public policies need to take into account climate change and adaptation objectives. This approach is broader and includes all components of public policies, including development and economic policy (e.g., with economic diversification as a vulnerability-reducing option), and governance and learning (O’Brien et al., 2012).

This approach is valid at national scale – for economic and development policies – and at local scale, for instance for urban plans (e.g., Lall and Deichman , 2011; Viguie and Hallegatte, 2012), where risk management and land-use planning are difficult to disentangle (Burby et al., 2001; Hallegatte, 2011).

The mainstreaming approach is also consistent with other trends in environmental policies: many analyses have concluded on the need to integrate risk management policies within development policies (Kellenberg and Mobarak, 2008; UN-ISDR 2009; World Bank and UN 2011), and climate mitigation is now approached more as a low-carbon development issue than as a purely environmental issue (Stern, 2006; World Bank 2010).

17.5. Economic Instruments to Provide Incentives

With the exception of insurance-related instruments there is relatively little literature on the use of economic instruments for adaptation. One reason is that, apart from insurance, few adaptation instruments work directly via economic incentives and through the use of markets. The potential of economic instruments in an adaptation context is, however, recognized. Agrawala and Fankhauser (2010) distinguish the following incentive-providing instruments relevant for key sectors: (i) Insurance schemes (all sectors; extreme events), (ii) Price signals / markets (water; ecosystems), (iii) Financing schemes via PPPs or private finance (flood defence, coastal protection, water); (iv) Regulatory measures and incentives (building standards; zone planning); (v) Research and development incentives (agriculture, health).

17.5.1. Risk Sharing and Risk Transfer, including Insurance

Risk transfer and risk sharing are economic instruments that shift disaster risk from one party to another. The IPCC SREX concluded that such mechanisms could lead to improved climate change adaptation as they generate post-disaster finance for relief, recovery, and reconstruction; help with reducing vulnerability; promote knowledge and provide incentives for reducing and managing extreme event risk (IPCC, 2012). Further, the SREX suggests, with medium confidence, that risk sharing and transfer mechanisms employed at local, national, regional, and global scales can contribute to building resilience to climate extremes. Risk sharing and transfer instruments, most prominently insurance, as supplied formally by the insurance sector, are dealt with in chapter 10. We discuss how insurance-related mechanisms as economic instruments directly lead to adaptation and provide (dis)incentives for adaptation.

Risk sharing and risk transfer can be achieved through formal and informal mechanisms. Informal tools include reliance on national or international aid, using remittances, selling assets and borrowing from moneylenders. Such mechanisms are common throughout the world and provide important financial resources post-disaster, yet they tend to break down for large, covariate events (Cohen and Sebstad, 2003). Formal mechanisms comprise insurance, including microinsurance, reinsurance, as well as national, regional, and global risk pooling arrangements. Formal risk transfer involves ongoing premium payments paid to an insurer or reinsurer in exchange for accepting coverage of a risk and a claim payment to the insured post event" (UNISDR, 2009). Formal insurance mechanisms are unequally distributed across regions and hazards. Insurance penetration in developed countries is considerable, whereas in many developing regions it is very low. In 2010 globally about 30% of disaster losses and 20% of climate related losses were insured. Markets differ substantially according to how liability and responsibility is distributed (Botzen et al., 2009; Aakre et al., 2010), and in many instances governments play a key role as regulators, insurers, or reinsurers in developed and developing countries alike (Linnerooth-Bayer et al., 2005).

Insurance-related instruments may directly and indirectly lead to adaptation. Two channels can be distinguished for the direct incentive effect: i) instruments provide claim payments after an event, and thus help to manage and reduce the follow-on consequences; (ii) they share systemic risks pre-event and allow for improved decisions allocating risk and return (Skees et al., 2008; Hess and Syroka, 2005; Hoeppe and Gurenko, 2006). The former channel exists by definition, and for the latter, although surprisingly there is little formalized reported evidence, most analysts would concur with Bernstein (1996), who suggests that "the capacity to manage risk [using insurance], and with it the appetite to take risk and make forward-looking choices, are key elements of the energy that drives the economic system forward." As one interesting example, farmers exposed to severe drought in Malawi were able to grow higher-yield, yet higher-risk crops which allowed them to increase their incomes after having been granted access to donor financed index-based microinsurance linked to loans in the form of farm inputs (Linnerooth-Bayer, 2011).

Risk sharing and transfer instruments may also indirectly lead to adaptation as the premium paid in the anticipation of risk can provide incentive to assess and finally reduce the premium by reducing risk. In order to price and understand risk, systematic risk analysis is required leading to improved understanding and awareness of risks (Botzen et al., 2009). Further, insurers may price risk differentially and offer premium discounts for risk reducing behavior. Evidence is not ample, as for one reason, there are important transaction costs associated with monitoring risk-reducing behavior. Yet, as one example, differential premium pricing for flood insurance offered according to flood zones in the UK has been effective in deterring further construction in high risk areas, although premium discounts are generally not granted for risk reduction (Kunreuther and Michel-Kerjan, 2009; Kunreuther and Roth, 1998). Further, risk reduction may become a contractual obligation in insurance arrangements. As one important example, the National flood Insurance program (NFIP) in the US requires communities to reduce risks before homeowners can access insurance for their homes (Surminski, 2010). Yet, overall the evidence base for such incentive effects is mixed and limited and in practice risk financing mechanisms can be ineffective or even provide disincentives for reducing risk ultimately leading to mal-adaptation.

One reason why the incentive effect is rather weak is that decisions regarding risk prevention and adaptation are often influenced by many factors beyond the narrow benefit cost optimizing. Kunreuther et al. (2009) found that most individuals underestimate the risk and do not base decisions to purchase hazard insurance solely on costs and premium, but are influenced by the desire to reduce anxiety, comply with mortgage requirements, and social norms. As one example if neighbors have bought insurance, other households would follow suit (Kunreuther and Michel-Kerjan, 2009). Further, purchasing insurance-related instruments may actually lead to disincentives for adaptation. Insured agents (households, farmers, governments) often reduce their risk-minimizing efforts after taking out insurance coverage. This is termed Moral Hazard, which suggests that absent additional benefits granted by the insurer, it is rational for agents to rely on the financial security provided by the contract and relax any further preventive efforts as the returns to those may be small. Ultimately, this may lead to the build up of risk and maladaptation over time (Rao and Hess, 2009). Related to the moral hazard phenomenon is that of under-insurance, which arises when agents expect that, in the event of a disaster, the public sector will provide assistance. This is referred to as the Samaritan's dilemma (IMF, 2008). While governments need to act as providers of last resort in the case of extreme events that are uninsurable or unaffordable, there can be a tendency for such protection to be provided even for less extreme cases and to result in under adaptation.

In theory, this problem can be dealt with by measures such as using deductibles in insurance policies (Swiss Re, 1998) or long-term contracts (Kunreuther and Michel-Kerjan, 2009). In practice however this remains a major concern of any disaster insurance clause (Linnerooth-Bayer et al., 2005).

17.5.2. Incentives Design

Through regulations, subsidies and direct intervention, there are many opportunities for policy makers to improve autonomous adaptive responses to climate change. However, a great deal of attention needs to be placed on design of these efforts so that they lead to efficient responses and are cost-effective while avoiding perverse results that run counter to the policy maker's objectives.

A basic tenet of efficient policy is that it affects the behavior of those who have the most to gain. For this reason, economists tend to favor voluntary actions with incentives, either positive or negative, over mandates or uniform policies. Examples of these include various Payments for Environmental Services (PES), which are discussed in 17.5.4. In principle, such payments schemes make it possible for those who benefit to make a deal with those who can provide the environmental services at the lowest cost. For example, payment for environmental services programs in Costa Rica offer a way for the downstream beneficiaries of watershed protection to pay upland landowners who protect the forest (Pagiola, 2008). With climate change the benefits of protection to the downstream parties may change but the presence of a PES scheme will make it easier to adapt to the changes.

A second consideration is cost efficiency, i.e. the extent to which governments make the best use of their resources. The measurement of the net effect of a policy is challenging because it is difficult to anticipate what would have occurred in the absence of the policy. Two important considerations are additionality and leakage. Lichtenberg and Smith-Ramirez (2011) measure both of these effects in the context of a conservation subsidy program in Maryland. They estimate that when calculating the net effect of the program on agricultural soil carbon sequestration, the net impact should be discounted by 0-20% because the subsidized practices might be non-additional, i.e., would have been adopted even without the subsidy. They also estimate that the net effect should be discounted by 0-20% due to leakage, i.e., to account for the fact that the subsidies encourage farmers to bring other land into production.

Finally, policies must be carefully designed to avoid perverse outcomes in which the aggregate outcome actually runs counter to the policy maker's objectives. A classic example of this is found in policies that encourage adoption of water-saving technology in arid regions. Peterson and Ding estimate that drip irrigation, which has an application efficiency that is 33% higher than that of center pivot sprinkler, actually leads farmers to increase total water use as they respond to greater efficiency by increasing the acreage under irrigation. This is more widely known as the rebound effect, whereby increases in efficiency of resource use result in more resources being demanded. In general it is best addressed by increasing the price of the scarce resource when efficiency gains from technological developments increase demand without increasing the supply of the scarce resource.

17.5.3. Loans, Public Private Finance Partnerships

The private sector has always been involved in the provision of public goods and is increasingly so now. Public Private Partnerships (PPPs) involve contracts between public and private sector entities with the aim of generating finance for the provision of public goods and increasing the effectiveness of project implementation and procurement. The rationale for governments is to reduce their financial cost by leveraging private funding, as well as to reduce the financial and operational risks involved in carrying out projects. Key instruments comprise public contracts, service concessions, and financial instruments including public guarantees for loans as well as concessional loans (see Bräuninger et al. 2011). As one area of activity PPPs have been standardly used for large infrastructure projects, and one relevant example is the Thames flood defence barrier in London set up in 1982, which is the world's second largest movable flood protection scheme protecting London and the Thames estuary from tidal surges and coastal flooding. Finance for this public works project was generated entirely by taxpayers, yet design, building supervision and construction were outsourced to the private sector. PPPs are being used for adaptation already. An example is the Drought Tolerant Maize for Africa Project initiated by the Consultative Group on International Agricultural Research (CGIAR) in partnership with national agricultural research institutes in the Sub Saharan region and elsewhere, NGOs and private sector seed providers. Funded by donor money, research institutes have developed many drought resistant maize crop varieties and successfully used the seed providers and community based organizations to have the seeds distributed and used by Sub Saharan smallholders (Agrawala and Fankhauser, 2008)

17.5.4. Payments for Environmental Services

The Millennium Ecosystem Assessment (2005) documented the linkage between ecosystem services (ES) and human well-being, specifically highlighting the role of ecosystem services in regulating climate, floods, diseases and water purification as well as in provisioning (see also Daily (1997) and Heal (2000)). Both the regulating and provisioning roles are important for climate change mitigation and adaptation, including food provision, natural shoreline protection against storms and floods, water quality maintenance, support of tourism and other cultural and spiritual benefits, and maintenance of the basic global life support systems (UNEP, 2006). Payments for environmental services (PES) are an increasingly popular innovative market-based approach to conservation that has been applied increasingly in both developed and developing countries to translate external, non-market environmental services into financial incentives for local actors to preserve the ecosystems that provide the services (Wunder et al, 2008; Wünscher et al, 2008; Engel et al, 2008). Ecosystem managers (for example, farmers) chose to convert land to uses such as conventional agriculture even though they often have negative effects (externalities) on other people (for instance, downstream water users) because of higher financial benefits associated with conversion. Those who are negatively affected could choose to pay the ecosystem managers (the ES providers) to induce them to adopt practices that ensure the provision of the ES. (Engel et al., 2008).

Though there are variations to the definitions of PES, the key features of a PES highlighted in these definitions include the voluntary nature of a transaction, the conditionality of a buyer securing provision from the supplier to guarantee payment, individual or collective decisions, social or private interests in the management of resources and transparency (Wunder, 2005; Muradian et al, 2010; Tacconi, 2012). Schemes can operate at various geographical levels, from the international (such as payments for REDD) to the local level involving individuals and businesses. In all cases, the role of intermediaries in PES schemes is emphasized.

The types of ecosystem services covered by PES schemes in the literature are wide ranging, including wildlife (Frost and Bond, 2008), bird habitats (Asquith et al, 2008), watersheds (Wunder and Albán, 2008; Asquith et al, 2008), carbon sequestration (Pagiola, 2008; Wunder and Albán, 2008), reforestation of agricultural land (Bennet, 2008), water (hydrological services) (Muñoz-Piña et al, 2008; Turpie et al, 2008; Pagiola, 2008), biodiversity (Turpie et al, 2008; Pagiola, 2008), agri-environmental services (Claassen et al, 2008; Dobbs and Pretty, 2008; Baylis et al, 2008), forests (Engel and Palmer, 2008). PES programs often differ substantially from one another as a result of different ecological, socioeconomic, political, institutional conditions and whether they are user-financed (in which funding comes from the users of the ES being provided) or government-financed (in which funding comes from a third party) (Wunder et al, 2008). Of the case studies analyzed by Wunder et al (2008), user-financed programs were better targeted, more closely tailored to local conditions and needs, had better monitoring and a greater willingness to enforce conditionality, and had far fewer confounding side objectives than government-financed programs.

PES approaches in developing countries, while growing, have met with mixed success. Focusing on payments for watershed services, Porras et al (2008) identified 50 ongoing schemes, 8 advanced proposals and 37 preliminary proposals. The main problems remain in the areas where the services are hard to define (such as biodiversity) and where the scheme is driven more by government aims and objectives and less by local needs. In such cases payments often do not guarantee the environmental improvements in spite of large outlays. As a result a number of schemes that were initiated in the early part of this century have been abandoned.

While there are ample cases of mitigation–focused PES schemes (e.g. Wunder and Borner (2011), Pagiola (2008), Wunder and Albán (2008)), there is little or no evidence of the use of PES approaches to climate change adaptation in the literature. Yet one has reason to believe that if the schemes are effective and well designed, they offer a framework within which adaptation to changing pressures on ecosystem services can be undertaken in an effective manner. In this context, Chishakwe *et al* (2011) draw comparisons and find synergies between community based natural resources management approaches (types of PES schemes e.g. in Frost and Bond (2008)) in Southern Africa and community-based adaptation to climate change.

17.5.5. Improved Resource Pricing (Water Markets)

Studies of adaptation to climate change in the water sector often begin by citing the prospect of future water shortages, and the potential for conflict among sectors (and sometimes among nations). One technique frequently cited for resolving these conflicts, while also encouraging water use efficiency, is the establishment of markets for water and water pricing schemes (e.g., Alavian et al. 2009; Vorosmarty et al. 2000, Adler, 2009). Traditionally markets facilitate the transfer of water from historical lower valued users to higher valued users under the cases of increasing demand or supply scarcity while prices convey scarcity values (Olmstead, 2010). A few studies make the case that, without water markets, or explicit pricing, the impacts of climate change could be much larger – citing the reform of water allocation policies along market lines as a key adaptation measure (Medellin-Azuara et al. 2008). In the most extreme cases, the projected increase in climate-induced water demand (particularly in the agriculture sector), coupled with a projected decrease in climate-induced effective water supply during critical periods (from the joint effect of altered seasonal precipitation and increased temperature), suggests that the water supply/demand balance can only be achieved by a choice between water rationing and water pricing.

In a number of countries, there remain a number of important institutional barriers to effective water pricing and marketing. These include a lack of property rights, limits on transferability, legal and physical infrastructures, affordability issues, and institutional shortcomings (Saleth et al. 2012) coupled with issues involved with return flows, third part impacts, market design, transactions costs, and average versus marginal cost pricing, (Griffin, 2012). Many countries have instituted structures for water pricing in the domestic and agricultural sectors. These include the creation of decentralized Water User Associations specifically tasked with implementation of water markets. Nevertheless tariffs for water are unevenly applied, collection rates are low, metering is rarely implemented (at least for the agricultural sector, which is typically the largest water user) and pricing structures are often based on annual rather than usage-based fees. Institutional and implementation issues often undermine incentives for water conservation and leak repair that represent one of the largest potential benefits of water pricing as an adaptation strategy. In addition, affordability issues remain a critical issue in low income countries that has not been adequately addressed to date (Alavian et al., 2009).

17.5.6. Charges and Subsidies including Land Taxes

The literature on environmental regulation over the past 30 years has emphasized the importance of market-based instruments (MBIs) as often more effective than command and control regulations in achieving the desired goals. They are found to be generally more cost effective and provide stronger incentives for innovation and dynamic efficiency than technology-based standards. Within the wide range of instruments that qualify as market based, there is a general preference in terms of overall efficiency for charges over subsidies (Sterner, 2002; Barbier and Markandya, 2012). Indeed one of the important sources of environmental misallocation of resources comes from environmentally damaging subsidies and removing these can generating significant environmental gains (Global Energy Assessment, 2012).

In the context of climate change the use of MBIs versus other instruments has focused more on mitigation rather than adaptation. Recently, however, some of the issues have been discussed in the adaptation context as well. The previous sub-sections have noted the benefits of insurance (17.5.1) and PES (17.5.4), which are essentially MBIs, as providing mechanisms for effective adaptation. The same applies to the role of improved resource pricing (17.5.5).

In many cases the impact of climate change is to exacerbate the effects of pricing resources at below their social costs. This is true for some forms of energy (e.g. hydro) as well as most of the ecosystem services, which are classified under the categories of provisioning (e.g. water, genetic materials), regulating (e.g. pollination, erosion control), and supporting (e.g. soil retention). Hence if these resources can be better priced the need for additional public sector adaptation measures will be lessened. In addition to the instruments already identified others that are potentially important include: raising the price of energy through a tax (Sterner, 2011), developing markets for genetic resources (Markandya and Nunes, 2012) and strengthening property rights and the legal frameworks so schemes such as PES can be more effective. While the case for such social cost pricing through the use of charges is strong, it also has its limitations. Higher prices for key commodities can hurt the poor and vulnerable. Some argue, however, that complementary policies are available to address such concerns and implementing the principle of social cost pricing remains a priority (Sterner, 2011).

Land use taxes are one type of taxes which may effectively provide incentives for adaptation to slow (sea level rise) and sudden onset change (climate extremes) by pricing location choices in exposed areas. The IPCC (2011) finds exposure of people and assets to have been the major driver behind rising disaster losses so the potential is large. Yet, overall land use taxes for steering behaviour in hazard-exposed areas, for many reasons including those related to political economy, have only been used sparingly so far (see Bräuninger et al. 2011).

17.5.7. Direct Investment

Investment in physical assets across all sectors is key part of the development of all economies. In response to climate change these investments will need to be modified, and a given level of service flows from roads, buildings etc. will require a greater initial investment (see Section 17.6). The World Bank study of the costs of adaptation divided its effects on the costs on infrastructure into price and quantity effects. The price effect is the cost of purchasing and maintaining the baseline level of infrastructure services while the quantity effect is the cost of meeting changes in demand for various services as a result of climate change (World Bank, 2009). The study attempted to estimate both but in the end only reported the price effects on the grounds that: (a) estimates of the impact of climate on investment in a given economic activity were difficult to determine based on historic data[1], (b) it proved very difficult to estimate the impact of climate on infrastructure quantities reliably given the variation due to country effects, which could not be modeled.

[FOOTNOTE 1: The links between investment in a given location and climate variables derived from historic data were considered unreliable as forecasts of how activities might be relocated as a result of climate change. The literature on path dependency provides solid evidence that the path of a country's future development depends critically on its current stock of assets, which in turn is co-determined with the current location of economic activity.]

This leaves a gap in the literature that remains to be filled. The economic viability of certain areas will be altered as a result of climate change and this may lead to either more or less demand for infrastructure. At present this remains difficult to determine with acceptable accuracy. Nevertheless some rough estimates made the Bank suggest that the quantity effect could be large: as much as 75% of the price effect. In aggregate terms net investment needs for infrastructure vary from US$14 billion to US$30 billion a year from now to 2050.[2]

[FOOTNOTE 2: Net investment estimates treat reductions and increases in investment demand symmetrically. Estimates are also made assuming that countries or regions that gain from climate in terms of reduced investment will not transfer funds to regions with deficits. So a country with a negative investment need has its investment set at zero when aggregating to get a regional and global figure. This is called the 'X-sum' and gives slightly different figures. World Bank (2009). Economics of Adaptation to Climate Change: World Bank, Washington DC.]

17.5.8. Norms and Regulations

Economic instruments that are used to provide incentives for a better allocation of resources are invariably accompanied by norms and regulations that allow these instruments to function effectively and that act to limit environmental degradation and a general overuse of resources. The instruments discussed in this section are no exception and need such regulations to function effectively. Examples include an obligation to take insurance against damage from extreme events, rules that allow markets to function and that define property rights in areas where PES schemes can operate, and requirements for the use of specific technologies that are resource efficient, such as water saving devices.

Care has to be taken when imposing technology standards as they can result in a high cost outcome compared to economic instruments that achieve the same goal with greater flexibility and lower cost (see 17.5.2).

Norms and regulations are also the appropriate instruments in situations where the wrong action can result in a great risk to other parties. Examples are bans of open fires when the risks of them spreading are high or the requirement to maintain drainage systems in good order when standing pools represent a breeding ground for mosquitoes.

The right norms and regulations can also be important to allow the most appropriate behavioral responses. For example the rules governing landlord tenant responsibilities can affect the way that they respond to incentives for energy efficiency (see 17.5.10) and rules making insurance companies offer longer term contracts and linking terms of insurance to the property rather than the owner can affect the willingness of occupants to invest in mitigation measures that have a longer term payoff.

17.5.9. Behavioral Approaches

Because individuals fail to take into account properly low-probability risks (Tversky and Shafir 1992), and because they do not weigh long term consequences consistently (Ainslie 1975), taking into account behavioral biases can increase the efficiency of policies. For instance, people treat differently abstract information on distant events, and concrete, emotionally-charged information linked with real-world experience (Trope and Liberman, 2003). In practice, this limits the impact of “dry”, emotion-free, information such as information on flood return periods (Fischhoff et al., 1978; Slovic, 1997). It is indeed well documented that individuals do not use the information that is available on natural risks when they make their choices (Magat et al., 1987; Camerer and Kunreuther, 1989; and Hogarth and Kunreuther, 1995). This is why, in other domains like driving rules, information is not only transmitted, but implementation is being monitored to make it become automatic (Engel & Weber, 2007). In the case of disaster risk management and risk awareness, it is well established that communication is more efficient if it goes beyond informing on probabilities and risks and provides information on how to react in case of extreme events, using specific examples and real-world stories. Moreover, people usually overreact when the rare event eventually does occur (Weber et al. 2004), leading to biased and under-optimal responses (Hallegatte, 2011). To avoid this problem, risk-management institutions need objective rules on which to base their decisions, such as in the Netherlands, where “acceptable risk levels” are defined as a function of population and asset densities.

17.5.10. Institutional Innovations

Section 17.3 mentions market failures as a reason why private adaptation alone would be inadequate. One example was the case of moral hazard and agency issues, when the agent making a decision concerning a risk is not the one who bears the resulting risk level. An example is the case of developers who build and sell housing, thus not bearing the risk they are creating if risks are not perfectly accounted for in housing prices. Another illustration is the owner-tenant relationship: when tenants pay energy bills, owners have little incentive to invest in insulation and low-energy heating and air-conditioning systems. Higher temperatures are thus likely to lead to higher energy consumption from AC than would be optimal with appropriate insulation and AC systems. These issues can be corrected by institutional innovation, such as specific schemes to make it possible for owners and tenants to share the benefits of investments in higher energy-efficiency buildings (Allcott and Mullainathan, 2010; ADEME, 2009). Another example is related to "risk-based" insurance, with premium calculated as a function of the risk level, which would be estimated as a function of assets' characteristics and locations. Such a scheme has been proposed in many countries to promote risk mitigation by households and businesses. In practice, a homeowner who invests in risk mitigation improvements (reinforced roof or windows) would benefit from a reduced insurance premium, helping finance the investment. But this approach is difficult to implement in practice with current one-year insurance contracts: the investment in risk mitigation produces benefits over decades and a homeowner who sells his house may not be able to recoup the benefits from its investment. This is why Kunreuther and Michel-Kerjan (2011) propose the creation of long-term insurance contract, attached to the property and not to the owner. Such a scheme would correct one important market failure in the insurance industry. Its success would however depend on the ability to solve other problems, and notably the one linked to the regulation of insurers and to the amount of risks they should be allowed to bear, relative to their capital.

17.5.11. Intellectual Property Rights

Technology transfer is increasingly seen as an important part of the set of measures needed for effective adaptation. Technology Needs Assessments carried out in developing countries list about 165 technical measures related to adaptation in the areas of agriculture, water, health and coastal zones where innovative solutions are being sought (Christensen et al. 2011). In many of these cases some of the technologies are covered by patents and other instruments for protecting intellectual property that act as a constraint to technology transfer. Often developing countries cannot afford to pay the patent price.

Quite a lot has been done to find a way round this problem in the area of health, where patent buy-outs, patent pools, compulsory licenses and other open source approaches have been used (Dutz and Sharma, 2012). Patent buy-outs involve third parties (e.g. international financial institutions or foundations) acquiring the marketing rights for a patented product and allowing a generic producer to sell it in a developing country market. Patent pools represent a group of patent holders who agree to license their individual patents to each other (closed pool) or to any party (open pool). They have been used recently by the drug purchasing facility UNITAID to set up a Medicine Patents Pool covering multiple patents. A foundation managing the pool then licenses them so that generic manufacturers can provide the drugs at affordable prices while patent holders get some royalties.[3]

[FOOTNOTE 3: A related scheme is one where the holder of the IPR agrees to make the technology available for no royalty. These are referred to as patent comments.]

Compulsory licenses are issued by governments, allowing patent rights to be overridden in critical situations. It is suggested that such a situation applies with climate change (Henry and Stiglitz, 2010). Where the issuance of compulsory licenses involves overriding international IPRs some international agreement would be required to work within the confines of international law.

Other than the case of compulsory licenses these mechanisms require a credible third party that brings together the holder of the IPR, governments of countries where the patents will be overridden and generic manufacturers. The owners of the IPRs can gain by having access to markets that they otherwise would not have access to. They may also be willing to participate in such agreements to fulfill their corporate social responsibility objectives. In both cases, however, they would want to ensure that these markets are segmented from the ones where they supply the drugs are supplied at a patent based price.

Health is one of the areas where adaptation to climate change will be required, and where developments in vaccines and treatments for vector borne diseases could be important. Hence these mechanisms for addressing IPR issues are directly relevant here. A similar approach can be applied in other areas such as seeds in drought prone or saline environments, water management technologies, pest management techniques etc. There is growing reliance on various forms of intellectual property in the management and control of genetic materials, which have a major role in any strategy for adaptation in the agricultural sector and where the constraints on the adoption of new technologies referred to above are also present. The issues involved include hybridization, plant breeders' rights (PBR), trade secrets, utility patents, genetic use restriction technologies, and trademarks and geographical designations (Boettiger et. al 2004). Various transaction mechanisms, including licensing and material transfer agreement, enable technology transfer among firms through an innovation supply chain that includes public and private sector institutions. Various forms of IPR have contributed to enhanced private investment in agriculture in industrial countries, yet it remains minimal in developing countries. (Naseem, Spielman, and Omano 2010).

Patent ownership by multiple owners has reduced access to technologies that are essential for the utilization of modern molecular biology in the development of new genetic materials. Furthermore, the fragmented intellectual property landscape may require a researcher to surmount high transaction costs in order to have the freedom to operate and overcome intellectual property constraints (Delmer et. al 2003). This problem is especially acute in developing countries, where public sector researchers are engaged in much of the development of new genetic materials and their adaptation for local conditions. Several collective institutions were introduced to remove intellectual property constraints and reduce transaction costs for biotechnology innovation. PIPRA, for example, provides a clearinghouse for intellectual property that assists developers of orphan technologies in accessing technologies that are originated in public research institutions (Graff et. al 2003). Another example is the African Agricultural Technology Foundation (AATF), which allows developers of technologies in Sub-Saharan Africa originated by the public and private sector.

While patents are defined nationally, intellectual agreements are evolving to harmonize intellectual property rights across borders, and trade related aspects of intellectual property are integrated in the WTO. The Convention on Biological Biodiversity aims to conserve biodiversity as well as protect the property rights of source regions of genetic material; it has to be further refined to enable access of plant breeders to genetic materials in terms beneficial to all parties (Boettiger et. al 2004). The various regulations of use of agricultural biotechnology methods, and in particular numerous promising genetically engineered traits in crops, has emerged as a major barrier to the development and diffusion of these technologies (NRC 2010). Development of a regulatory framework that will address concern for safety and enable utilization of modern crop breeding technologies that expand capacity in order to adapt to climate change remains a major policy challenge.

17.5.12. Innovation, R&D Subsidies

Subsidies comprise direct payments (grants), tax reductions or price support by a government to a private sector actor in order to support the implementation of an activity (Gupta et al., 2007). There has been some criticism as to the efficiency of subsidies in terms of leading to rent seeking and adverse effects on competitiveness; yet it is an instrument category popular with decision-makers and the wider public. In principle, subsidies may be employed to incentivize any investment into adaptation as well as behavioural change (Bräuninger at al., 2011). Subsidies are mostly used for many reasons other than climate adaptation, yet in several countries they have already been applied for adaptation. However, beyond commentary and proposals, the evidence base particularly in terms of spurring and incentivizing R&D is very limited.

Bräuninger et al. (2011) suggest that subsidies may be used for a number of activities and sectors, of which particularly agriculture stands out due to its high exposure to weather variability and climate change. Grants can generally be employed for a broad variety of adaptation efforts providing cost-effective incentives if this direct payment is constructed to just provide for an adequate return to the actor implementing the activity. In this regard, grants can be made to support any R&D efforts. As one example, in agriculture, research and development regarding new crop cultivars may be directly supported and spur innovation. Tax reductions can contribute to R&D efforts related to adaptation and one example is exemption from VAT effectively lowering the break-even point for innovative products. As another instrument, price support given to private sector actors may provide particularly strong effects in agriculture. This instrument can be used to promote specific drought-resistant crops. As well, support may be extended for the market introduction of novel technology such as air conditioning and cooling applications in buildings or flood protection devices.

17.6. Costing Adaptation

17.6.1. Review of Existing Global Numbers: Gaps and Limitations

There have been a limited number of global and regional adaptation cost assessments over the last few years (World Bank, 2006; Stern, 2006, Oxfam, 2007; UNDP, 2007, UNFCCC, 2007;, 2008; World Bank, 2010). These estimates exhibit a large range and have been completed mostly for developing countries. Global adaptation costs range from $48 to $171 billion annually, and US$28-67 billion per year for developing countries alone.

[INSERT TABLE 17-3 HERE
Table 17-3: Estimates of global costs of adaptation.]

IPCC (2012) considers confidence in these numbers to be low, as they fall into only three independent lines of evidence. The World Bank (2006) estimates the cost of climate proofing foreign direct investments (FDI), gross domestic investments (GDI) and Official Development Assistance (ODA), which was taken up and modified by the Stern Review (2006), Oxfam (2007) and UNDP (2007). UNFCCC (2007), the second source of cost estimates, calculated existing and planned investment and financial flows required for the international community to effectively and appropriately respond to climate change impacts. Thirdly, the World Bank (2010) follows the UNFCCC (2007) methodology and improves upon this by using more precise unit cost estimates, the inclusion of costs of maintenance as well as those of port upgrading as well as the risks from sea-level rise and storm surges.

As discussed by Parry et al (2009) the estimates are thus interlinked, which explains the seeming convergence of the estimates in later studies. As well, Parry et al. (2009) consider the estimates a significant underestimation by at least a factor of two to three and possibly higher if also including other sectors such as ecosystem services, energy, manufacturing, retailing, and tourism and considering the fact that the adaptation cost estimates are based mostly on low levels of investment due to an existing adaptation deficit in many regions. Thus the numbers have to be treated with caution.

17.6.2. Consistency between Localized and Global Analysis

Adaptation costs and benefits are derived for two main purposes. Most studies are done on sectoral and project levels, where cost and benefit estimates may inform investment decisions in terms of type and timing of investments. In principle, the idea is to maximize net benefits in terms of avoided damages (the benefits) less the adaptation costs. The underlying benefit and cost accounting may go beyond financial flows and incorporate social and equity considerations. Also, estimates may be used, as often done in CBA, to select the most favorable projects amongst alternatives.

Global and regional estimates on the other hand are generally estimated to derive a “price tag” for overall funding needs for adaptation, which then can be used to help in identifying appropriate international, domestic, and private funding sources. These estimates generally follow the *Investment and Financial Flows* (I&FF) methodology and do not aim at estimating benefits (Agrawala and Fankhauser, 2008). The global estimates also tend to put greater emphasis on achieving geographic and (to a lesser extent) sector comprehensiveness of coverage, and as a result may tolerate somewhat less precise data and methods than sectoral and local studies.

Given the different purposes and methodologies of the available studies, it is unsurprising that it is very difficult to compare “local”, i.e, national and sectoral, with global numbers. In terms of available studies, sectoral studies cover relatively well coastal zones and agriculture, for which geographical detail is reasonably good. Less is known and many gaps remain for sectors such as water resources, energy, infrastructure, tourism and public health sectors, and assessments have predominantly been conducted in a developed country context (see Table 17-4 for an overview of costs and benefits assessment).

[INSERT TABLE 17-4 HERE
Table 17-4: Coverage of adaptation costs and benefits.]

However, as Fankhauser (2010) notes, with the sole exception of coastal protection costs, adaptation costs have shown little convergence across estimates, nor is there convergence of sectoral to global costs. Fankhauser suggest that that the global cost estimates using the I&FF methodology estimate the "true" costs of adaptation. The World Bank (2010) study is innovative in terms of taking a two-track approach assessing both national (7 cases) and global adaptation costs. For a number of country studies (Bangladesh, Samoa and Vietnam) a comparison of adaptation costs was made, and results in terms of cost in terms of GDP were broadly in reasonable agreement. For strengthening infrastructure against windstorm, precipitation and flooding, for the studies of country at high risk, costs were considered to be 10-20% higher compared to what global (average) numbers would suggest, largely owing to the ability of country-level studies to consider at least some socially contingent impacts.

17.6.3. Selected Studies on Sectors or Regions

The focus in this section is on studies that best illustrate the current state-of-the-art in the estimation of costs and benefits of adaptation, with a particular focus on support of adaptation decision-making. Within that class of work, there are two broad categories of economic analyses of adaptation at the sectoral level: econometric and simulation approaches. Econometric studies generally looks at adaptations that have happened across climate regimes and relies on historical cross-sectional, time series, or panel data to infer the effects of adapting to climate across space or time. Within the econometric category, there are Ricardian studies (which relate to land values, or to profitability, e.g., Mendelsohn et al 1994, Deschenes and Greenstone (2007)) and more generic correlational approaches (e.g., Schlenkeret et al. (2005) linking temperature and precipitation to crop yields and in the livestock sector Seo and Mendelsohn (2008)). Both can be used to estimate the marginal effect of climate on impacts, incorporating adaptation, and in some cases they can infer types of adaptation strategies employed.

The key advantages of an econometric approach are reliance on real-world data, "natural experiments" in some cases, and an ability to reflect the joint costs and benefits of multiple adaptation strategies to the extent they are employed together in real world. The econometric approach does not require the analyst to simulate all adaptation mechanisms, only to establish that there is a robust relationship is between a climate stressor and the outcome of interest. The data required to implement the approach, at its simplest level, are limited to seasonal climate and economic output and may be more generally consistent with current availability in many countries, so the approach also has the advantage that it can be applied broadly. The key disadvantages of the Ricardian approach are an inability to trace transmission mechanisms of specific adaptation measures or to isolate the marginal effect of these strategies or measures; the inability to transfer estimates out of context (e.g., an African study does not apply to Asia, where the climate, adaptation, and social context all differ and affect the marginal costs and benefits of adaptation measures); and that the statistical estimation can be challenging and sometimes subject to multiple interpretations (Schlenker et al (2005)). Finally, the econometric approach is limited in its ability to consider adaptive actions that are beyond the scope of current observations, particularly actions that might prove beneficial in responding to large increases in extremes or even changes in carbon dioxide concentrations that have not been experienced in the historical record.

A second class of economic studies involves simulation modeling. The simulation approach traces costs and benefits of adaptation strategies through mechanisms of interest, typically through a series of climate-biophysical-behavioral response–economic components. Within simulation modeling there are two main threads in the behavioral response/economic component of the simulation. The first involves rational actors who consider the benefit and cost consequences of their choices and pursue economically efficient adaptation outcomes, and the second involves a decision-rule or reference based characterization of the response of actors to climate stressors. As noted below, in many sectors the state-of-the-art begins with the simpler decision-rule based approach, and may progress to consider benefits and costs, and then perhaps to consider other factors, such as equity and nonmarket values.

A separate issue from the benefit and cost estimation method is the perspective adopted with respect to the goals of adaptation. Some studies adopt the perspective that the goal of adaptation should be restoring pre-climate change (or current) level of service: these studies are typically for sectors where the analytic tools are in their infancy. Major drawbacks include implicit assumptions that current service can be restored without residual impacts, and the lack of attention to whether restoration is a cost-effective response. The alternative and typically more mature perspective involves an economic evaluation within the study that compares costs and benefits of adaptation options, and their distributional consequences, implicitly acknowledging that planners have a choice along a broad continuum concerning whether to invest in adaptation or tolerate impacts and/or residual impacts, depending on their relative magnitude. The decision-making framework can focus not only on whether to adopt an adaptation measure, but also the scale or extent of its implementation (e.g, how much sand to place on a beach to protect a dune from sea-level rise and storm surge). A potential drawback of this approach is the difficulty in knowing and estimating all costs and benefits of adaptive measures or suites of measures.

17.6.3.1.Transportation

Adaptation studies in the transport sector are most common for roads. The key analytic issues have been of a primary nature: assembling useful geocoded inventories of potentially vulnerable transport resources/networks, and parameterizing climate stressor/response relationships from the engineering literature (Transportation Research Board 2008). The latter typically represent a new transformation of existing information on the sensitivity of roads to existing climate variability. One of the first studies to overcome the inventory issue is Larsen et al. (2008), a simulation modeling approach that assumed perfect foresight and which focused on Alaskan infrastructure, but that study relied on rules of thumb for the stressor-response component. Larsen did however provide some key insights about the benefits of adaptation, showing substantial net gains from investing in adaptation, particularly in modifying and optimizing capital replacement and maintenance cycles. A few studies that have made progress on both inventory and stressor-response fronts include World Bank (2010), at a global and country scale; Chinowsky et al. (submitted) for regions of southeast Asia, and Chinowsky and Price (submitted) for the US. Across this literature, the scope of economic adaptation estimates includes paved and unpaved road maintenance and replacement, freeze-thaw effects, ice roads, and some attention to rail susceptibility to extreme temperature.

The remaining challenges include moving beyond perfect foresight to incorporate more realistic learning and baseline road maintenance norms, particularly in developing country contexts; generating an econometric literature as a cross-check on these simulation approaches; and addressing extreme events. Econometric approaches could start with a cross-sectional approach that relates spatial differences in temperature and precipitation regimes with construction costs and/or specifications, for instance. A key challenge with an econometric approach for public infrastructure is that it is currently not built to optimize revenue returns – without tolls, there is no revenue stream, only a service stream that is not quantified.

Some indirect effects of climate on transport are beginning to be explored. An example is a case study on transport of agricultural products and climate change adaptation (Attavanich et al. submitted). That study aims to investigate the effect of climate change on interregional grain transportation flows in the US due to climate-induced shifts in geographic crop production patterns – the results suggest that while current adaptive capacity for shifts in transport demand may be high, some planned actions, such as new navigation infrastructure, could enhance capacity.

17.6.3.2.Agriculture and Forestry

Adaptation is a fundamental agricultural and forestry issue as producers have adapted to accommodate local conditions and continue to adapt regarding extreme events, altered prices and pest populations among others factors. In terms of economics agriculture and forestry adaptation issues have been examined from three principal viewpoints (Aisabokhae et al, 2011). Studies have been done that:

1) Examine the *economic choices that producers make* to adapt to climate. The basic assumption is that one gains insight into adaption possibilities by examining the ways economic choices vary over locations and times with varying climate conditions. Generally this is done using econometric methods. Numerous studies have been done where for example: a) Chen and McCarl (2001) find that US pesticide costs increase as climate warms indicating adaptation to climate induced increased pest populations; b) Seo and coinvestigators (e.g. Seo et al , 2008, 2009, 2011) find that the localized mix of African, South American and Australian livestock is climate sensitive and that livestock offer substantial adaptation strategies. c)

South American crop mix adapts to climate (Seo and Mendelsohn 2008); d) Land use allocations adapt to climate with hotter conditions causing African and US farmers to adapt by moving land from crops to pasture (Seo et al, 2009; Mu and McCarl, 2011) along with causing alterations in livestock stocking rates (Mu and McCarl, 2011) ; e) Zhang et al (2011) who finds that US producers adapt to climate by changing livestock breeds. Chapter 20 also cites evidence about changes in crop management observed in a number of developing areas. Finally, other studies while not explicitly examining adaptations, argue that their underlying models incorporate the effects of full farmers' adaptation (e.g. spanning from the US study of Mendelsohn et al., 1994; to the African study of Schlenker, and Lobell , 2010).

2) Examine the *economic implications of potential adaptation possibilities*. The basic effort is to simulate the implications of pursuing adaption possibilities. In terms of citing a few specific examples: a) Butt and McCarl (2006) examine the consequences of migration in cropping patterns, development of heat resistant cultivars, reduction in soil productivity loss, cropland expansion, and changes in trade patterns in Mali indicating that such adaptations increase production, reduce producer income, raises welfare of consumers and reduce the proportion of the population at risk of hunger; b) Sohngen et al., (2001) find that adaptations cause an increase in global timber production as producers in low-mid latitude forests (South America, Oceania, Asia-Pacific, and Africa) adopt more productive short-rotation plantations; c) Aisabokhae et al (2011) examine the US value of alternative adaptations ranking them in value finding crop management has the highest value followed by crop mix, and irrigation use; d) Chen et al (2012) examine the amount of trade liberalization or technical progress needed to overcome the global negative effects of climate change on rice production; e) McCarl et al (2009) find that substantial technical progress is needed in the US southwest to adapt to climate change effects and f) Finger et al. (date) examine irrigation as an adaptation strategy in Switzerland finding adoption of irrigation leads to higher and less variable maize yields but with small economic benefits.

3) Examine the *economic implications of implemented adaptation practices*. While adaptation has been widely discussed there are not very many ex post appraisals of climate change adaptation practices. However there is a rich literature on evaluating projects that use strategies that could be used in climate change adaptation (For example ex-post evaluations of the consequence of crop varieties (Pal, 2011) or irrigation project development (White and Masset, 2008)). These examine rates of return and implications for income distribution and poverty. Also there are studies that address autonomous adaptations undertaken by producers (e.g., Mendelsohn and Dinar (2003) argue that in Brazil and India adaptation is successful since there are smaller observed yield changes under climate change than under agronomic results). There are also studies that show unexpected maladaptation results from potential adaptation practices where for example conservation subsidies on irrigation have lead to increased area planted and overall increased water use.

17.6.3.3. Energy

Hydropower is the main electricity source in Brazil, sharing 87.5% of currently total generation. In a simulation presented in Margulis et al (2011), based on a downscaling of climate scenarios using the Hadley Center modeling system, the reliability in the hydropower system would be affected when comparing IPCC A2 and B2 pathway scenarios under climate change impacts, to equivalent scenarios without those impacts. Climate change would affect the hydropower system due to a change in water availability, with a reduction in firm energy ranging between 31.5% and 29.3% in 2035. Impacts would be extremely acute in the North and North East regions while minimal or even positive in the South and South East regions. Although 96.6% of the electricity production capacity is interconnected in a national grid, which makes compensation easy between regions, positive effects would not offset the losses.

The outputs of an optimization model revealed that to cope with climate change, an extra generating capacity of between 162 TWh and 153 TWh per year (respectively 25% and 31% of the domestic supply of electric energy in 2008) would be required, preferably from natural gas, sugarcane bagasse and wind. The new configuration of the energy system would have an additional capital cost of between US$48 billion and US$51 billion with operational costs ranging from US$ 6.9 to US$ 7.2 billion.

17.6.3.4. Sea-Level Rise and Coastal Systems

As outlined in SREX, adaptation in the context of sea-level rise (SLR) and response to coastal risks is one of the better studied and understood sectors – as a result, economic analyses are well-developed and extensive. One reason that the adaptation literature is characterized as generally more advanced than other sectors is that the direction of SLR is clear, and uncertainty mainly centers around the magnitude and timing of effects (unlike precipitation effect, for example - see Argawala and Fankhauser (2008)). Most current studies adopt a simulation modeling approach, focus on property and other human values at risk, and model responses by assuming optimal economic behavior (based on benefit/cost criteria) and perfect foresight in adapting. A more limited literature examines other indicators of coastal risk (e.g., risks to coastal wetlands and mangroves), attempts to model learning and behavior rather than economic-based responses, or considers such nuances as the dual nature of natural coastal ecosystems as both systems at risk and systems that provide protection for human uses (Kreeger et al. 2010). Some of the best examples of the current state-of-the-art at the global or regional scale are Nicholls and Tol (2006) for a broad range of resources at risk, using a combination of benefit/cost and other economic criteria to estimate response; Hanson et al. (2011) focused on ports; Neumann et al. (2010) using a benefit-cost criteria but with detailed site-specific data at a regional scale; Pendleton et al. (2008) for regional scale (state of California) with broad consideration of effects; and Hudgens and Jones (submitted) for effects on coastal wetlands, using an innovative habitat equivalency analysis (HEA) to estimate economic impacts on nonmarket resources, as reflected by net primary productivity.

The question of scale noted above is critically important for SLR analyses. Overall, the spatially comprehensive and global analyses (such as Nicholls and Tol 2006) achieve that goal at the cost of relatively less spatially resolved analysis, which makes it useful for characterizing global scale adaptation cost-effectively, but with significant uncertainties. These approaches are less useful at the national and sub-national scale (see World Bank 2009), but very useful for incorporating the economics of adaptation in global integrated assessment models. Regional scale analyses can sometimes achieve comprehensive, high resolution spatial analysis (see Neumann et al. 2010) but may omit nonmarket impacts. Local-scale analyses (see Purvis et al 2008) can incorporate detailed uncertainty analyses and probabilistic approaches to optimal adaptation response. Often the limiting factor in trade-offs between scale and resolution is availability of high-quality elevation and resource valuation data, especially in developing countries.

As a general point, studies focus on effects on built environment and beach resources, with less or no consideration of ecosystem services such as those provided by wetlands (storm surge absorption and buffer, fisheries nursery, bird viewing, ecosystem primary productivity and biodiversity). Storm surge is starting to be integrated as a key process for impacts which interacts with rising sea-level (World Bank 2009 Mozambique country study; Neumann et al. 2012/submitted, Vietnam and Mozambique study) – these studies have demonstrated methods for application of the economics of adaptation even in data-sparse environments. Other innovations include estimation of the benefits of coastal adaptation by applying the concept of Coastline Equivalent Length, where the estimated value of each type of at-risk asset (urbanisation, utility networks, etc.) is converted into a coastline extension whose protection would have the same value. If the population per unit length of coastline (PCL) and the per capita GDP value are known, one can establish a value for the GDP/km of coastline (GDP-CL). Cities with a high GPD-CL value are those with a high value assets exposed to rising sea levels, provided a proxy measure of economic assets at risk.

Some researchers have begun to address other indirect effects of SLR, such effects on agricultural markets and prices from inundation of rice production areas (Chen et al. 201X – submitted?) As knowledge of direct SLR impacts grows, and in particular knowledge of combination of SLR and storm surge, indirect effects of both adaptation actions (e.g., building seawalls diverts capital that might otherwise be invested in development or production to defensive measures) and residual impacts (e.g., abandonment and residual impacts lead to fragmentation of social capital and resulting regional economic damages) are beginning to be incorporated.

Innovative new work has also compared the costs and benefits of soft adaptation options, such as coastal management policies. A Brazilian study looks at costs for coastal zone management policy implementation relative to value of resources, and finds the value of resources at risk are much larger than costs of funding policy reforms –

in this case the costs of adaptation management actions account for less than 3% of the endangered coastal heritage value.

17.6.3.5. Health

The health costs of adapting to climate change are based on expected impacts through vector-, water- and food-borne diseases, as well as thermal stress caused by heat waves and negative impacts of malnutrition (McMichael et al., 2004). Quantitative estimates of these impacts are bedeviled with a cascade of uncertainty, arising not only from a lack of knowledge about the increased risks of individual health outcomes but also because of changing baseline conditions (baseline risks are expected to fall with development) and changes in demographic make-up of areas with an elevated risk (Ebi, 2008). Nevertheless estimates have been made based on median increases in incidence across a range of scenarios, addressed through a combination of anticipatory (e.g. vaccination, water treatment) and reactive (e.g. increased cost of treatment of people who fall ill) measures. One set of measures simply seeks to reduce all additional impacts (leaving a zero residual damage). The study looks at vector- water and food- borne diseases only and is considered an underestimate as it does not include some personal costs as well as some infrastructure and health care maintenance costs (Ebi, 2008). The case for going for a zero residual target is strong if one compares the additional costs with the costs of increased morbidity and mortality for those left untreated. For example the cost per death avoided through disease control programs focusing on combined health interventions is of the order of US$ 300-600. On moral grounds most of us would find it unacceptable to believe that a life is not worth that much in even the poorest country. (Markandya and Chiabai, 2009).

17.6.3.6. Buildings and Urbanism

Many studies have been published in recent years on climate change impacts and adaptation in urban areas, even though most of them are qualitative and do not provide quantitative or economic evaluations (Hunt and Watkiss, 2011). Also, most of them focus on market impacts (e.g., asset losses due to disaster) and disregard non-market impacts (e.g., loss of attractiveness due to reduced comfort). These analyses have also focused on two hazards linked to climate change: heat waves and health (e.g., Dessai, 2003; sometimes the analysis accounts for local air pollution, e.g., Bell et al., 2007), and floods, both from rivers and extreme rainfall (e.g., Ranger et al., 2011) and coastal (e.g., Suarez et al., 2005).

Hallegatte et al. (2011b) proposes a methodology to assess adaptation actions in cities, stressing in particular the need to account for non-market impacts, but also for indirect and systemic losses that are particularly important in urban areas. Indeed, beyond the direct impact of climate change and extreme events, any impact on city infrastructure has an impact of all economic activities. These effects are well documented for disasters, such as, e.g., hurricane Andrew (West and Lenze 1994); the 1993 Midwest Floods (Tierney 1995); the 2003 European heatwave (Létard et al., 2004); and hurricane Katrina (Hallegatte, 2008). In non-disaster situations, climate change direct impacts are also likely to create indirect impacts in urban areas; for instance, a reduction in building thermal comfort can energy demand and affect housing prices, with widespread economic consequences (Hallegatte et al., 2007). Because there are direct and indirect impacts, adaptation actions can target direct and/or indirect impacts. For instance, some adaptation actions such as building dikes aim at reducing the direct losses due to floods; other actions can aim at facilitating reconstruction and recovery with insurance and government support in case of disasters, thereby reducing indirect losses. In non-disaster circumstances, some adaptation actions can reduce direct losses (e.g., improving thermal comfort to maintain summer tourism); and other actions can target indirect losses (e.g., creating alternative activities to make it possible for workers to shift from negatively-affected sectors).

Different approaches and tools are used to investigate these two categories of adaptation options: assessing direct impacts is usually done using highly-detailed sector-scale analysis and models (e.g. Rosensweig et al. 2009), while the taking into account of indirect impacts requires multi-sector, systemic analysis and models, which are often based on simpler assumptions and methods (e.g., Ranger et al., 2011). These two examples can be summarized as follows:

- Rosensweig et al. (2009) investigates adaptation actions to reduce the vulnerability to heat waves in New York City, USA. To do so, they use a regional climate model (NCAR MM5) to assess how changing surface conditions (e.g., by planting trees or grass) would change the temperature during a heat wave (see Table 17-5). Using a cost-benefit analysis, they conclude that high-albedo surfaces may be a more cost-effective way to reduce electricity demand when compared with tree planting or green roofs. They mention however that non-market co-benefits (such as air quality or reductions in the city's stormwater runoff) could improve the cost effectiveness of strategies involving vegetation.
- Ranger et al. (2011) provides an example of analysis that covers both direct and indirect impacts in the city of Mumbai, in India. It investigates the consequences of floods with different return periods, with and without climate change; the effect of climate change is from a weather generator that downscales simulations from one global climate model. Non-climatic drivers such as population and economic growth are not included, and the analysis investigates the impact that climate change would have on an unchanged city. Table 17-6 summarizes these results, for the 50-, 100-, and 200-year return periods, suggesting that the direct loss from a 100-yr event could rise from $600 million today to $1890 million in the 2080's, and total losses (including indirect losses) could rise from $700 to $2435 million. These impacts translate into adaptation options, some targeting direct losses (e.g., improved building quality, improved drainage infrastructure) and others targeting indirect losses (e.g., increased reconstruction capacity, micro-insurance). The analysis suggests that improved housing quality and drainage could bring total losses in the 2080's below current levels (i.e. more than compensate for the effect of climate change), and that full access to insurance would halve indirect losses for large events.

[INSERT TABLE 17-5 HERE
Table 17-5: Average and maximum differences in urban air temperature simulated with MM5. Average differences were computed over all grid cells and heat-wave days and times and rounded to one decimal place. The maximum is the largest temperature difference in any grid cell at any hour on any of the heat-wave days. Each value is the difference between the temperature of the warmer land surface cover type and the cooler land surface cover type. For example, the simulated urban air temperature associated with tiles representing trees is on average 0.6°C cooler then the urban air temperature associated with tiles representing grass. Because the average difference between impervious surface and trees is 1.9°C, this implies that planting street trees is approximately 3 times as effective per unit area as planting trees in open space.]

[INSERT TABLE 17-6 HERE
Table 17-6: Upper estimation of total losses (direct+indirect, including loss in housing services) due to various types of events in present-day and future conditions.]

17.6.3.7. Water

O'Hara and Georgakakos (2008) assess the opportunity of storage capacity expansion under climate change in San Diego (USA), using a cost-benefit analysis of the water system, taking into account the cost to import water, changes in demand and an analysis of uncertain parameters. Although the resulting costs are not precisely stated, climate change is found to be costly, with expected costs in the hundreds of millions of dollar. At the scale of the California water system, Medell´ın-Azuara et al. (2008) evaluate the change in operation for a dry-warm climate change scenario, using the CALVIN engineering economic optimization model. Taking into account the opportunity costs of the different projected demands, they find a rise in scarcity and operating costs, which may be considerably offset by adaptation measures, prominently by transferring water from agriculture to cities. In CALVIN, climate warming results in earlier peak storage, and changes in groundwater and surface operating rules. Kirshen et al. (2005) study the country-wide supply adaptation to climate change in China, by determining the groundwater and surface water yield change under climate change. Reservoirs are aggregated and their yield is assessed using the secant peak algorithm, while costs for groundwater extraction are also taken into account. Changes in yield are found to be different among basins. The annualized cost of meeting a given supply target is also determined for three major river basins, for the current climate and two IPCC model climate change scenarios. The results differ by location and scenario, with the HadCM2 model costs always higher under climate change, while with the CCC model, costs are lower and potential yields are higher in two basins.

Ward et al. (2010) is a global scale study that assessed the future needs of municipal water over the world, with and without climate change, by computing the costs of reaching a water supply target in 2050. The aggregation level used is the food producing units level, and storage capacity change, using the secant peak algorithm to determine the storage yield relationship and alternative sources of water are considered. They find that baseline costs exceed adaptation costs ($73 bn p.a versus $12 bn p.a.), most of the adaptation costs (83-90%) being in developing countries.

17.6.3.8. Ecosystems and Ecosystem-Based Adaptation

There have been a number of approaches to valuing the costs of climate changes to ecosystems. Velarde et al (2005) quantifies the economic costs of climate change impacts on protected areas at a very disaggregated level in Africa. Downscaled results from four Global Circulation Models (GCMs) are used to classify different ecosystems in accordance with the Holdridge Life Zone (HLZ) system. A benefits transfer approach is then used to place an economic value on the predicted ecosystem shifts resulting from climate change in protected areas. The results provide approximations for the impacts on biodiversity in Africa under the business-as-usual scenario established by the Intergovernmental Panel on Climate Change (IPCC) for the middle and end of the 21st century.

Marine and ocean-based ecosystems are a key area for future work (see Chapter 6, section 6.4). Some new work looks at economic impacts of coral reef losses, but mostly estimating economic impacts, as planned adaptation options to respond to coral reef loss are few (Chen et al., submitted; Martinich et al. submitted). While there is a great need for economic analyses of response options as outlined in Section 6.4 most current work focuses on autonomous adaptation through markets (e.g., fisheries losses adapted through changes in target species, engaging in aquaculture, or shifting livelihood).

17.6.3.9. Recreation and Tourism

Recreation and tourism account for a substantial share of consumer spending in rich countries and substantial income in destination countries. Supply of tourism services employs many people and is a dominant or very important activity in many regions. Recreation and tourism encompass many activities, some of which are more sensitive to weather and climate than others. Climate change would affect the place, time and nature of these activities. (reference?)

In particular climate and weather are important factors in tourist destination choice and climate change may stimulate adaptation. Tourists might adapt to climate change in three ways. First, they may change their tourism destinations as studied by (Maddison, 2001) (Lise and Tol, 2002) (Bigano *et al.*, 2006) (Bigano *et al.*, 2007; Hamilton *et al.*, 2005a; Hamilton *et al.*, 2005b) (Scott *et al.*, 2008b) (Gössling and Hall, 2006) (Hamilton and Tol, 2007). Tourists have a clear preference for the climates that are currently found in Southern France, Northern Italy, Northern Spain, California, Hawaii, Costa Rica, Colorado and other locations. Climate change adaptation might alter destination choice to higher latitudes and altitudes. Tourists from currently cool places, such as Northwestern Europe or the Northern US, would be more inclined to spend the holiday in their home country.

However, tourists may also change the timing of activities. For instance, people may decide – if work and school permit – to take their holiday in September rather than August. As a third response, tourists may decide to change their holiday activities, perhaps because the time is fixed by school and the location by the ownership of a holiday home, and opt for a relaxed rather than an active holiday.

There is also a considerable literature on adaptation by suppliers of tourism services. Ski resorts have been well-studied. Adaptation options include artificial snow-making (Elsasser and Bürki, 2002)(Hamilton *et al.*, 2007) (Scott *et al.*, 2008a) (Scott *et al.*, 2003) (Scott *et al.*, 2007) (Steiger and Mayer, 2008) (Pickering *et al.*, 2010), alternative tourism activities in winter (Scott and McBoyle, 2007) (Bicknell and McManus, 2006) and promotion of summer use (Serquet and Rebetez, 2011, Loomis and Crespi,),plus development of economic activities outside tourism (Bourdeau, 2009)(Pickering and Buckley, 2010)(Moen and Fredman, 2007).

There are fewer studies on beach resorts. (Phillips and Jones, 2006) survey the various options to prevent beach erosion due to sea level rise. (Hamilton, 2007) finds that tourists are averse to artificial coastlines, so that hard protection measures against sea level rise would reduce the attractiveness of an area.

17.6.3.10. Natural Disaster Risk

Bouwer (2010) estimates future losses (the benefits of adaptation action) from river flooding to a Polder area in the Netherlands. Most such studies have varied climate and weather, but kept other drivers constant. This risk based study is one of the few that aims at identifying the key factors driving future losses under climatic, land use and exposure change. The study arrives at a wide range of increases in losses of between 96 and 719% by 2040 as compared to 2010. Exposure (asset) changes are identified as the key driver. These estimates are without additional measures taken and thus represent a large share of the *costs of inaction*. Other work by Blankespoor et al. (2010) estimates costs of extreme events in developing countries worldwide, and then suggests that investments in economic development as an adaptation measure might effectively neutralize the economic growth impacts of extreme events associated with climate change. Most studies in this area use relatively crude measures of extreme events linked to climate change, as the GCMs tend to be best at forecasting changes on a monthly time scale, and most extreme events are on a weekly to daily time scale. New work by Mendelsohn et al. (2012) couples a cyclone track estimation tool from Emanuel et al. (2008) with econometric estimates of damages indicating climate change could double impacts from the wind component of tropical cyclones. These efforts hold promise for adaptation analyses, for example providing insight on the magnitude of “rainy day funds” that could be set aside for future emergency response (*ex post* adaptation and response), but the current econometric tools are focused on impacts rather than estimating the costs and benefits of specific *ex ante* adaptation measures, such as land-use change, building code improvements, and floodproofing.

[INSERT FIGURE 17-3 HERE
Figure 17-3: Assessing future flood losses (Bouwer, 2010).]

17.7. Summary

[in process]

This chapter has noted in a number of places that ‘softer’ options for adaptation have a relative advantage: they avoid taking actions that are irreversible and costly while they themselves consist of measures that are flexible and that can be modified as and when more information becomes available. Such measures include education and awareness-raising, moral suasion, and instruments such as taxes, charges and trade policies. Of all of these the last set, which can broadly be classified as economic instruments probably offer the greatest potential. Examples would be the following:

- Increasing charges for resources that will become scarcer with climate change. Principal among these is water.
- Improve the functioning of insurance markets to cover individuals facing increased risks due to extreme events, along with other measures to reduce impacts. This is a cost-effective way to adapt to increased variability as long as the insurance markets are competitive, as long as the individuals are able to afford the costs of insurance and other adaptation and as long as they do not discount future impacts too highly or under-adapt due to the ‘Samaritan’s Dilemma’[4] (IMF, 2008). The public sector can have a role to play in: (a) providing limited insurance cover where private insurers are unable to provide it (but only when this is due to market failure and not because the risk is too high – see below), (b) acting to correct market failures that result in the private sector undertaking too little insurance, such as applying too high a discount rate or acting in expectation of the Samaritan’s Dilemma and (c) subsidizing poor households who are unable to afford the insurance or offering them alternative livelihoods in the light of the increased costs of climate

variability. Thus the public sector measures have to be designed in full awareness of how individuals will act.

- Some energy firms are already major users of weather derivatives. For example, weather derivatives can hedge exposure to colder than expected winter, reducing impacts on consumer bills. These can be used to stabilize revenues, control costs and manage cash reserves. Unfortunately these instruments are mainly used in the US, although recently there have been some transactions in Australia and India (ESMAP, 2011)
- In the same vein, trade can help address some climate impacts. In the energy sector for example, trading power across borders can reduce the national impact of extreme events (to the extent the covariance of these events is low across countries) and help diversify the energy system making it more resilient to climatic variations. (ESMAP, 2011).

[FOOTNOTE 4: The Samaritan's Dilemma is the tendency for under-insurance by those who expect external help in the event of adversity: those supplying the help would wish to limit its extent by committing to relatively low support—but their benevolence means they cannot do so credibly.]

Frequently Asked Questions

FAQ 17.1: Given all the significant uncertainty about the effects of adaptation measures, can economics contribute anything to decision-making in this area?

- Economic methods have been developed precisely to address decision-making in the face of uncertainty. Indeed some of these have already been applied to the evaluation of adaptation measures. There are different method, varying with the underlying information and data.
- Where probabilities can be attached to different outcomes arising from an adaptation measure, economic tools such as risk and portfolio theory allow us to choose the measure that maximise a function, which compares not only the net benefits of each measures, but also the risks associated with the measures (e.g. the possibility of a very poor outcome).
- In some cases it is difficult to place values on some outcomes (e.g. disasters involving large scale loss of life). An alternative to the risk or portfolio theory approach can then be used, that looks for the least cost solution that keeps probable losses to an acceptable level.
- In situations where probabilities cannot be defined for different outcomes of adaptation decisions, the analyst can define scenarios that describe a possible set of outcomes from an action. In such cases economic tools have been developed that search for solutions that meet some criteria of minimum acceptable benefits across a range of scenarios, allowing the decision-maker to explore different levels of acceptable benefits in a systematic way, provided "acceptability" can be defined.
- There are still questions on how to apply these methods (particularly when the changes caused by climate change are non-marginal), and how to improve the quality of information on the possible impacts and benefits

For further discussion see Section 17.3.8 of chapter 17.

FAQ 17.2: Are economic approaches likely to bias adaptation policy and decisions against the interests of the poor, vulnerable and ecosystems?

- A narrow economic approach focuses on the costs and benefits of an action and provides this information to the decision-maker. But even in that case the final decision is not based on just this information. Account is also taken of who gains and loses (the distributional effects of the action), and of the impacts of the measures on factors that are not reported in monetary terms. If one only relied on the narrow economic information, decisions could be biased against the vulnerable and against measures that are more protective of the environment and other impacts that are non-quantifiable in monetary terms. But that is hardly ever the case: the economic data often feeds into a broader decision-making framework as one component (an important component given the limited resources available for addressing adaptation). Other factors are also important and at the end of the day the decision on what action to take is a political one. What is important is that this decision-framework is broad, equal weight being placed on economic and non-economic factors.
- A frequently used framework within which economic data is included along with other information is multi-criteria analysis (MCA) and examples of the application of this method are available in the chapter (Section 17.3.9). This framework provides for the inclusion of an uncertainty indicator as an additional criterion as well

as winder impacts of the measure that are not adequately covered in the economic assessment. MCA methods have been widely used but an issue that remains problematic is what weights (including equity weights) to attach to the different criteria.

- Another economic approach is to attach monetary values to non-market impacts, for example to changes in the services provided by ecosystems. The numbers are less certain than those attached to market impacts but they are still useful in extending the economic assessment and providing a way of comparing market and non-market impacts.

For further discussion see Sections 17.1, 17.2 and 17.3.9-17.3.11 of Chapter 17.

FAQ 17.3: In what ways can economic instruments be deployed to facilitate adaptation to climate change in developed and developing countries?

- Economic instruments (EIs) are designed to make more efficient use of scarce resources and to ensure that risks are more effectively shared between agents in society. In the context of adaptation, EIs help us ensure that the starting point for any adaptation policy involves an efficient use of the resources that will be impacted by climate change. This means that there is less impact to address through adaptation measures: for example if water is already priced properly, there will be less overuse that has to be corrected through adaptation measures. Second, if the instrument is in place and socially accepted, adaptation can take the form of a change in the price that is charged. With the same example, if climate impacts result in increasing water scarcity it is easier to adjust the water tariff than it is to introduce water pricing in the future in difficult circumstances and less costly than finding new ways of increasing supply.
- Insurance is another economic instrument used as a means of risk sharing. Where risks can be well defined insurance markets can help reduce vulnerability as well as generating funds for post disaster recovery. The presence of such markets can also provide incentives for insured parties not to take unnecessary risks, as premiums often depend on the assessed risk for individuals.
- Payments for environmental services (PES) schemes are also voluntary market based economic instruments operating in developed and developing countries for the effective use and management of resources such as water, forests, wildlife etc. Even though they are still evolving, they are highly relevant to climate change adaptation.
- Market based instruments have the important property of reducing the pressure on the government to undertaken protective measures. However, markets do not always work by themselves and they do need public action and support in many cases. The form of public intervention needs to have economic and non-economic dimensions. The insurance markets for example, do not cover all risks and their issues of affordability, which mean that public-private partnerships are often required. The public sector also has in important role in making voluntary market instruments work effectively through establishing the legal frameworks that define property rights over scarce resources such as land and water in areas where such rights are not well established. PES schemes, for example, can only work effectively when the public sector ensures that rights are defined and agreements honoured. The state can also help modify behaviour in situations where individuals fail to take account of low probability risks, thus resulting in a higher cost emerging from a private market system. Effective public action in such cases is not necessary in the form of economic incentives.

See Section 17.5 of Chapter 17 for more details.

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Table 17-1: Methodologies for the economic assessment of climate change and adaptation.

Approach	Description	Examples	Advantages	Limitations
Economic Integrated Assessment Models (IAM)	Global aggregate economic models that assess damage costs of climate change, and costs and benefits of adaptation. They develop values in future periods, expressed in $and %GDP as well as Present Values (PVs).	Global analysis of the costs and benefits of adaptation, with regional breakdown, e.g. Hope (2009) and de Bruin et al, (2009).	Provide global total estimates of benefits. Very flexible generating a wide range of potential outputs, including total PVs. Have been used to provide economic information on global climate policy.	Very aggregated approach with highly theoretical forms of adaptation, containing little technological detail or consideration of uncertainty (see Patt et al, 2009). Insufficient detail for national or sub-national adaptation planning.
Investment and Financial Flows (IFF)	Financial analysis. Early studies estimate costs of adaptation as percentage increase against future baseline investment expenditure. More recent national studies estimate the marginal cost increase needed to reduce climate risks to acceptable levels.	Global analysis of adaptation costs presented in UNFCCC, 2007. National studies using detailed approach advanced by UNDP (UNDP, 2009) and now piloted in 19 countries worldwide.	Provides estimates of short-term investment needs for adaptation. Use flexible methods that can be applied without detailed analysis of climate change.	Often no integral linkage with climate change scenarios, uncertainty, concrete adaptation strategies, or practical adaptation decision-making (though, in principle, can be included).
Computable General Equilibrium models (CGE)	Multi-sectoral and macro-economic analysis for economic costs of climate change, and emerging analysis of adaptation	National level estimates for autonomous adaptation, e.g. Carraro and Sgobbi (2008), and national planned adaptation costs, e.g. Kemfert (2006). Analysis of sectoral adaptation costs now emerging, e.g. coastal adaptation costs in Bosello et al (2011).	Captures cross-sectoral, market linkages in economy wide models (e.g. global, regional or national scales), including autonomous market adaptation, Can represent global trade effects.	Utilises aggregated representation of impacts and adaptation, no technical detail, no consideration of uncertainty. Omits non-market effects. Not suitable on its own for detailed national or sectoral-based planning.
Impact-assessment - scenario based	Projected future physical impacts and associated welfare costs of climate change derived using climate model outputs and sectoral impact functions/models, complemented by comparison of costs and benefits of selected adaptation options.	Global scale, e.g. World Bank EACC (2010) world rice technology and trade adapting to sea level (Chen , McCarl and Chang, 2012)).. European scale (e.g. Watkiss et al. for a wider range of sectors (2011). National sector specific scale (e.g. UK Flooding (Evans et. al. 2004) , Mali Agricultural sector actions involving welfare and poverty reduction (Butt, McCarl and Kergna, 2006))	Sector specific analysis at global, regional, national or sub-national scale. Provides physical impacts as well as welfare values. Can include non-market effects.	Does not represent cross-sectoral, economy-wide effects. Tends to treat adaptation as a menu of hard (engineering-) adaptation options to respond to specific defined scenarios. Medium to long-term focus of impact assessment may mean less relevance for short-term policy.
Impact assessment – extreme weather events. Risk assessment.	Variation of IA approach above, using historic damage- loss relationships from extreme events applied to future projections of such events. Adaptation costs estimated on basis of replacement expenditures or analysis of response options. Risk based variations include probabilistic analysis and thresholds.	Sub-national and sector applications, e.g. – OECD (2009); EAC study (2009) for 9 case studies, American Hurricanes and crop acreage adaptation (Chen and McCarl, 2009) Widely applied in flood risk management analysis (coastal / river) within cost-effectiveness framework for defined levels of protection.	Allow consideration of future climate variability, in addition to future trends. Provides information on short-term priorities (associated with current climate extremes). As above, but risk based context allows greater consideration of risk and uncertainty.	May be inappropriate to apply historical relationships to future socio-economic conditions. Robustness limited by the current high uncertainty in predicting future extremes. Risk based approach introduces extra dimension of complexity with probabilistic approach.

Impact assessment - econometric based	Variation of IA approaches above. Historical relationships between economic production and climate parameters derived using econometric analysis - and applied to future scenarios – that identify cross-sectoral differences to adaptation to current weather sensitivity	Often applied at the national sector level, notably for agriculture (e.g. Mendelsohn, 2000; Dinar et al., 2009.	Can provide information on economic growth and allow analysis of longer-term effects. Provide greater sophistication with level of detail.	Mostly focused on autonomous or non-specified adaptation. Very simplistic relationships to represent complex parameters. No information on specific attributes.
Adaptation assessments	Economic analysis of adaptive management (including adaptive capacity and iterative (dynamic) adaptation pathway).	National scale methods and applications emerging (e.g. Hunt and Watkiss, 2011) and some sectoral applications for coastal floods (EA, 2010). Farm level analyses have also been done (Kaiser et al, 1993 as have sectoral analyses (Aisabokhae et al 2012)	Stronger focus on immediate adaptation policy needs and decision making under uncertainty and greater consideration of diversity of adaptation (including soft options) and adaptive capacity.	Resource intensive analysis.
Adaptation methods identification	Analysis of the way that practices change as climate is altered	Finds autonomous strategy adjustments to climate alterations (Pesticide usage Chen and McCarl, 2001, Crop and livestock use Seo and othes, 2008, 2010 and Stocking rate Mu and McCarl, 2011)	Sector specific analysis at regional, national or sub-national scale. Identifies adaptation possibilities. Provides adjustments. Can be couples with examination of non-market effects.	Limited to observed adaptations and conditioned to climate changes that can be presently observed.

Source: Updated and expanded version of material in Watkiss and Hunt, 2010

Table 17-2: Examples of ancillary benefits.

Citation	Setting	Nature of Ancillary Benefits
Becken , S., 2005	Adaptation measures for tourism on tropical islands and their positive or negative ancillary effects	Water quality, ecosystems, pollution, amenities
Butt, McCarl and Kergna, 2006	Adaptation actions for the Malian agricultural sector	Reduction in the risk of Hunger for the population
Markandya, A. and Chiabai, A., 2009	Adaptation action to address increased risk of water borne diseases through improvements in water supply and sanitation	Improved quality of life and less burden of diseases from current climate factors
Egbendewe-Mondzozo et al 2011.	Health benefits from African Malaria control and their increased value as climate change proceeds	Rural income, education, labor supply
Khan, S et al 2009	Benefits of strategies to enhance food production in the face of many factors including climate change and population growth	Water use, water quality, energy consumption, GHG emission, food production
Attavanich et al 2011a,b.	Implications of crop mix adaptation in the US to climate change	Changes in duck populations and associated recreational value, needed infrastructure developments, changes in economic activity at alternative ports.
Frihy, 2001	Impacts of select coastal developments in Egypt some of which are possible adaptation actions	Benefits and costs are realized and number of strong costs are illuminated regarding adjacent regions illustrating maladaptation possibilities
Markandya and Mishra, 2011	Causing improved water efficiency in India by imposing metering and associated charges	Reduced state and central level fiscal deficits, reduced externalities from construction projects

Table 17-3: Estimates of global costs of adaptation.

Study	Results (billion USD/year)	Time frame	Sectors	Methodology and comment
World Bank, 2006	9-41	Present	Unspecified	Cost of climate proofing foreign direct investments (FDI), gross domestic investments (GDI) and Official Development Assistance (ODA)
Stern, 2006	4-37	Present	Unspecified	Update of World Bank (2006)
Oxfam, 2007	>50	Present	Unspecified	WB (2006) plus extrapolation of cost estimates from national adaptation plans (NAPAs) and NGO projects.
UNDP, 2007	86-109	2015	Unspecified	WB (2006) plus costing of targets for adapting poverty reduction programs and strengthening disaster response systems
UNFCCC, 2007	28-67	2030	Agriculture, forestry and fisheries; water supply; human health; coastal zones; infrastructure	Planned investment and Financial Flows required for the international community
World Bank, 2010	70-100	2050	Agriculture, forestry and fisheries; water supply; human health; coastal zones; infrastructure	Improvement upon UNFCCC (2007): more precise unit cost, inclusion of cost of maintenance and port upgrading, risks from sea-level rise and storm surges.

Table 17-4: Coverage of adaptation costs and benefits.

Sector	Analytical Coverage	Cost Estimates	Benefit Estimates
Coastal Zones	Comprehensive	√√√	√√√
Agriculture	Comprehensive	-	√√√
Water	Isolated case studies	√	√
Energy	N. America, Europe	√√	√√
Infrastructure	Cross-cutting, partly covered in other sectors	√√	-
Health	Selected impacts	√	-
Tourism	Winter tourism	√	-

Source: Agrawala and Fankhauser (2008)

Table 17-5: Average and maximum differences in urban air temperature simulated with MM5. Average differences were computed over all grid cells and heat-wave days and times and rounded to one decimal place. The maximum is the largest temperature difference in any grid cell at any hour on any of the heat-wave days. Each value is the difference between the temperature of the warmer land surface cover type and the cooler land surface cover type. For example, the simulated urban air temperature associated with tiles representing trees is on average 0.6°C cooler then the urban air temperature associated with tiles representing grass. Because the average difference between impervious surface and trees is 1.9°C, this implies that planting street trees is approximately 3 times as effective per unit area as planting trees in open space.

Difference between land surface types	Relevant mitigation strategy	Average (°C) (over all grid cells and times of day)	Maximum (°C) (in any grid cell at any time of day)
Grass minus trees	Trees in open space	0.6	1.7
Impervious minus trees	Street trees	1.9	4.8
Impervious minus grass	Green roofs	1.4	3.2
Impervious minus high albedo	High-albedo roofs and surfaces	1.1	2.6

Table 17-6: Upper estimation of total losses (direct+indirect, including loss in housing services) due to various types of events in present-day and future conditions.

Type of Event	Projected Flood Losses ($ million USD)					
	Present-Day			2080s		
	Direct Losses	Indirect Losses	Total Losses	Direct Losses	Indirect Losses	Total Losses
Simulated July 2005	1910	425(18%)	2335			
50-yr RP	570	95(14%)	665	760	130 (15%)	890
100-yr RP	600	100 (14%)	700	1890	415 (18%)	2305
200-yr RP	600	100(14%)	700	1990	445 (18%)	2435

Note :In parenthesis is the contribution of indirect economic losses to the total losses.

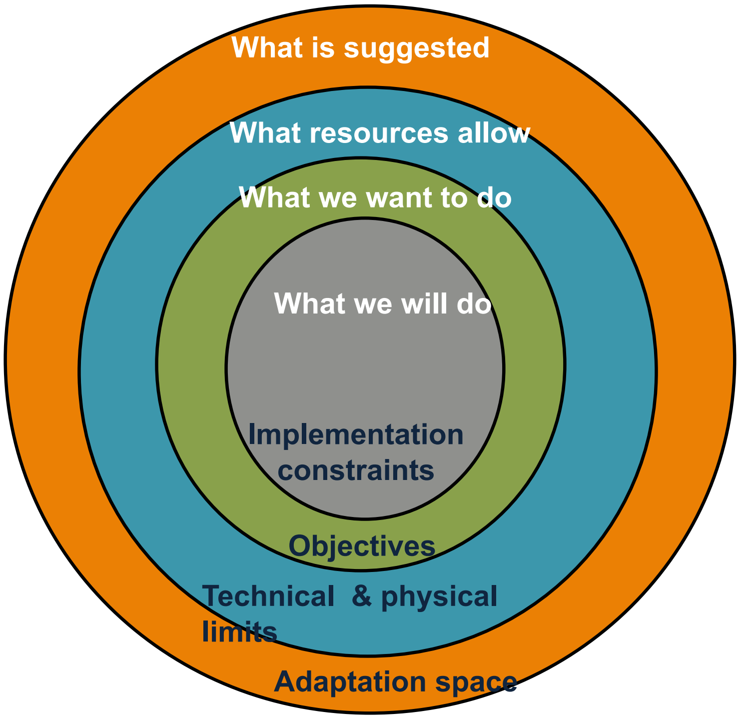

Figure 17-1: The narrowing of adaptation from suggested adaptations to what will be done. Forces causing the narrowing are listed in black.

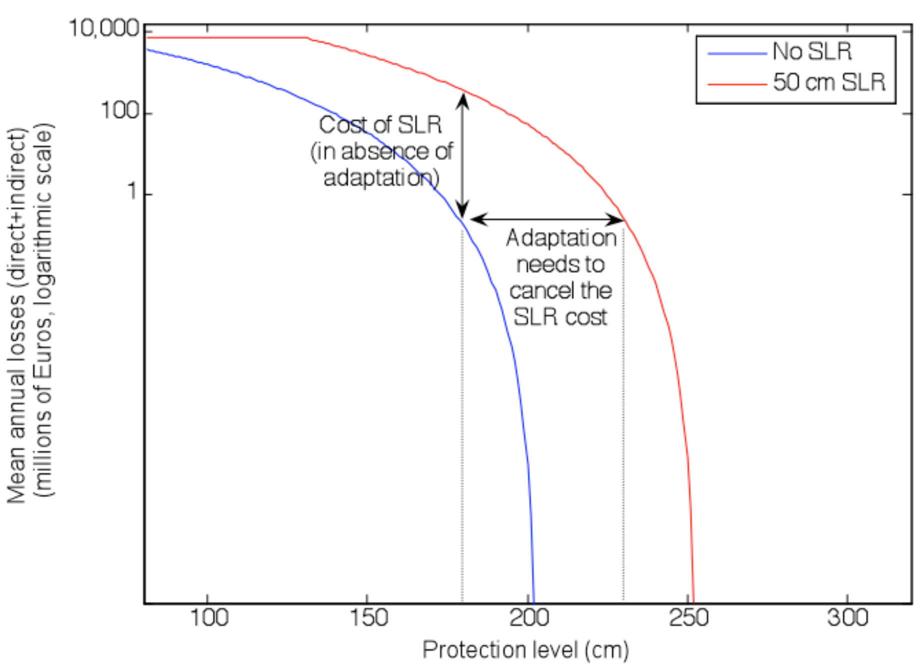

Figure 17-2. Illustrative example assuming a homogenous protection at 180 cm above current mean sea level (in the ‘No SLR’ and ‘50 cm SLR’ cases). The vertical arrow shows the cost of SLR in the absence of adaptation. The horizontal arrow shows the need for adaptation to maintain unchanged mean annual losses.

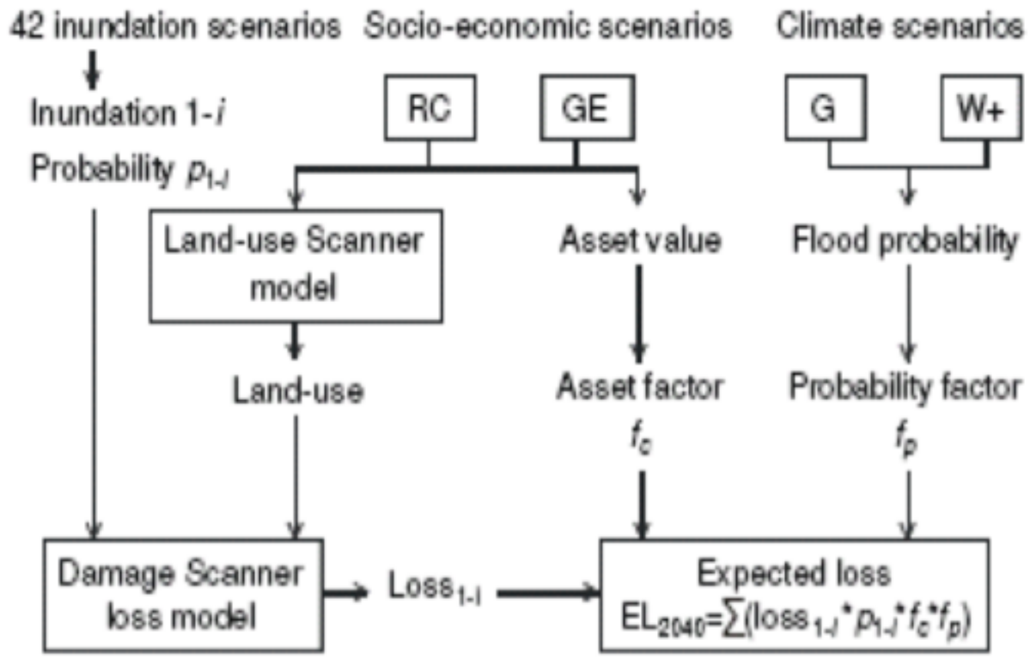

Figure 17-3: Assessing future flood losses (Bouwer, 2010).