Chapter 17. Economics of Adaptation

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Executive Summary

In the presence of limited resources and a range of goals, adaptation implies trade-offs between alternative policy goals *(high confidence)*. Economics offers insights into these trade-offs and into the wider consequences of adaptation. It also helps to explain the differences between the potential of adaptation and its achievement as a function of costs, barriers, behavioral biases, and resources available. [17.3.2, 17.3.3, 17.3.4] Economic analysis of adaptation is broadening from an emphasis on efficiency and market solutions to include 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. 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. [17.5.4, 17.3.6.3, 17.3.6.4]

Economics offers several types of insights into the following aspects of adaptation policy *(high confidence)*:
- The monetary dimension of costs and benefits [17.2.1]
- The assessment of non-market costs and benefits [17.2.1, 17.3.7.3]
- Estimation of the distributional consequences of adaptation and its impact on poverty [17.2.1, 17.2.7]
- The relationship between adaptation and development [17.2.7]
- The types of adaptation 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]

- 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 [17.3.5]
- Although the theoretical basis for economic evaluation of adaptation options is clear, there is little experience of practical application of this approach to adaptation problems. There is however extensive experience of applying the concepts and methods underlying the economic framework in other contexts, which is useful for designing climate adaptation policies. [17.6.1].

Economics provides important inputs to the evaluation and ranking of adaptation options in the face of uncertainty (*high confidence*). Approximate approaches are often necessary because of the lack of data or because of uncertainties about the nature of climate change or the efficacy of adaptation actions. A range of economic tools helps to address these uncertainties and helps design policies that are acceptable with a range of preferences and 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 attributed to different objectives. [17.2.6.1, 17.2.6.4, 17.3.5, 17.3.7]

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 co benefits such as alleviating poverty and enhancing development especially in developing countries *(high confidence)*. Ancillary effects may be a source of market failure. Many aspects of economic development also facilitate 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 with existing policies, referred to as "mainstreaming". [17.2.7, 17.4.4]

Existing incentives will lead to private adaptation actions. But public action to support adaptation is justified by the public goods nature of knowledge and much of the required infrastructure, by market failures, by the distributional impacts of climate change, and by behavioral biases. 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, norms and regulations, behavioral approaches and institutional innovations. [17.4, 17.5]

Risk financing mechanisms at local, national, regional, and global scales contribute to increasing resilience to climate extremes (*medium confidence*). Applicable mechanisms comprise informal and traditional risk sharing, such as relying on kinship networks, as well as market-based instruments including microinsurance, insurance, reinsurance, and national, regional and global risk pools. 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*). Price signals associated with risk financing can provide incentives for reducing risk, yet the evidence of effectiveness is weak and the presence of many counteracting factors actually often leads to disincentives, which is also known as *moral hazard*. [17.3.4, 17.3.6, 17.4, 17.5.1]

Estimates of the global costs of adaptation continue to improve, but remain inconsistent in methods, sectoral coverage, purposes, and time frames. The most recent estimates suggest a range from $75 billion to $100 billion per year globally by 2050, but important omissions from these estimates suggest the high end of this range could be much higher, and important shortcomings in the data and methods available for costing adaptation suggest the low end of this range could be substantially lower (*low confidence*).

- Defining the benefits and cost of adaptation is difficult, limited by data, and depends on value judgments. Estimating adaptation costs poses methodological, practical and moral difficulties, with consequences for how adaptation can be funded. [17.3.6.3, 17.3.6.4, 17.3.10, 17.3.11, 17.6]
- The existing estimates of global adaptation cost could be higher if sectors such as ecosystems, tourism, and socially contingent effects are included, and if the adaptation deficits of developing countries are more fully

taken into account. The global figures are based on only a few lines of evidence [17.6], and cover a selected number of sectors.

- Some evidence suggests that incremental adaptation costs increase over time as climate change unfolds (*low confidence*), but consideration of current adaptation deficits suggests that costs could be high in the short-term as well, and inconsistencies in the effect of economic development on adaptation capacity also confound the reliability of estimates of the trend over time [17.6.3].

Adaptation costing studies suffer from the absence of a robust community of practice, with great inconsistencies in the purposes, methods, data quality, and sectoral coverage of these analyses, limiting attempts to aggregate the finer-scale study results across regions and time [17.6.3]. Among these regional and local-scale analyses desirable characteristics include: a broad representation of relevant climate stressors to ensure robust economic evaluation; consideration of multiple alternative and/or conditional groupings of adaptation options; rigorous economic analysis of costs and benefits across the broadest possible market and nonmarket scope; and a strong focus on support of practical decision-making that incorporates consideration of sources of uncertainty [17.6.3]. Few current studies manage to achieve all of these objectives.

17.1. Background

This chapter assesses the literature on the economics of climate change adaptation, building on the Fourth Assessment Report (AR4) and the increasing role that economic considerations are playing in adaptation decision-making and policy. AR4 provided a limited assessment of the costs and benefits of adaptation, based on narrow and fragmented sectoral and regional literature (Adger *et al*, 2007). Substantial advances have been made in the economics of climate change after AR4. A key economic message from this literature is that the benefits of early action are greater than the costs of inaction. The literature also addresses the economic problem of climate change as a global market failure that is characterized by risk and uncertainty.

Adaptation action and policy has also advanced since AR4, and the literature on the economics of adaptation has reflected this. This chapter builds on other chapters in this assessment, in particular Chapter 2, which sets the basis for decision-making, recognizing economics as a decision support tool for both public and private actors. The type of economic approach used depends on factors discussed in Chapter 2 among others, including the agent making the decision, the nature or type of decision, the information used to make the decision, who implements the decision, others affected by the outcomes and the values attached to those outcomes. While realizing the linkages between adaptation and mitigation, the starting point of this chapter is that adaptation is a given need.

17.2. Adaptation as an Economic Problem

There are many adaptation strategies, and when considering these we need to judge whether the benefits outweigh the costs, with benefits and costs broadly defined. We have to consider current and future benefits, costs and resource usages, as well as uncertainty. Non-economic goals (concerning equity or environmental targets) are also of importance, as are efforts to achieve goals at highest net benefit or lowest net cost.

17.2.1. Reasons for Public Provision of Adaptation

Adaptation actions can be autonomous or planned. Some planned adaptations are public goods, which need to be put in place by elements of broader society (governments, NGOs, international organizations etc.). Their role exemplifies the classical economic definition of a public good, which is generally provided by an agency acting on behalf of a group of people. Economic analysis shows that market forces will under-provide such goods (Samuelson, 1954). Other reasons for public provision of certain adaptation measures include the existence of:

- Divergence between the social and private discount rates (i.e. different valuations of the future)
- Differences in risk aversion and risk perception between society and private individuals
- The value that society places on resolving inequities caused by climate change
- Possibilities for maladaptation where actions on behalf of one party worsen another’s adaptation status

- Barriers to adaptation arising from lack of resources (human, financial, technical, etc.)
- Land ownership or property rights patterns that preclude private adaptation efforts on affected lands
- A desire to facilitate adaptation in unmanaged but highly vulnerable areas.

17.2.1.1. Broad Categorization of Adaptation Strategies

There are many possible adaptation actions, as indicated in chapters 14 and 15. In economic terms these include:

- Direct capital investments, including in infrastructure (e.g. dams and water management)
- Technology development through research (e.g. crop varieties)
- Creation and dissemination of adaptation information (through extension or other communication vehicles)
- Human capital enhancement (investment in education)
- Redesign of or development of new adaptation institutions (e.g. forms of insurance)
- Changes in norms and regulations to facilitate autonomous actions (e.g. building codes)
- Changes in individual behavior
- Emergency response procedures and crisis management

Not all adaptation involves investment or is costly. Some adaptation measures involve modification of recurring expenditures as opposed to new investments (replacing depreciated equipment with more adapted items). Sometimes it involves changes in behaviors and lifestyles (e.g. due to increased frequency of heat waves).

17.2.1.2. Broad Definition of Benefits and Costs

The consequences of adaptation decisions cannot be expressed comprehensively only through the standard economic accounting of costs and revenues. Adaptation decisions can also affect:

- Income distribution and poverty (Jacoby et al, 2011)
- Macroeconomic performance (see, e.g., Fankhauser and Tol, 1995);
- Allocation of funds with a crowding out effect on other investments (Hallegatte et al., 2007) and future technical progress (Hallegatte and Dumas, 2008)
- Welfare of current and future generations through non-monetary effects
- Changes in regional distribution of economic activity, including employment
- Alterations in non-market factors such as water quality, ecosystem function, and human health.

17.2.2. Toward a Realistic Assessment of Strategy Attractiveness

Adaptation cannot reasonably overcome all climate change effects (Parry et al 2009). Some adaptation options will simply be too costly (from now the words cost and benefit will be broadly used as discussed in 17.2.1.2). Additionally social and political willingness to act and scarcity of resources will limit strategy adoption and preclude complete adaptation. 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 factors that will make the use of all adaptation strategies and complete adaptation impossible in a reasonable time scale. First, the sheer magnitude of the earth system suggests one cannot cancel all impacts (e.g., it is impractical to restore outdoor comfort under high temperatures). Second, certain processes (species extinction, melting of an ice cap) may be irreversible in any practical time period. Third, resource and knowledge availability plus uncertainty limits adoption. Fourth, adaptation measures may not be consistent with other policy objectives and priorities (i.e. competition for resources). Fifth, implementation barriers, obstacles, financial constraints and other market failures may constrain adoption (see Section 17.3).

17.2.2.1. Adaptation as a Dynamic Issue

Adaptation is not aimed at going from one stable situation to another. The challenge is to continually adapt to a "perpetually changing" climate (Hallegatte, 2009). Fundamentally adaptation is a long-term transitional process.

Many adaptations have long lasting effects like construction of seawalls or discovery of drought resistant crop genes. The optimal levels of investments with upfront costs and persistent benefits increase when the benefits are more long lasting or when climate change damages accumulate slowly (Wang and McCarl,2012). However, dynamic maladaptation is also possible as protecting now can expand investment in vulnerable areas and worsen future vulnerability (Hallegatte, 2011).

17.2.2.2. Funding Project-Based Adaptation

Adaptation to climate change is generally thought to be most efficient if it is mainstreamed into existing activities and processes (needs a reference). However, adaptation actions financed by external sources (e.g., multilateral or bilateral adaptation funds, research and development funds) are usually organized in discrete fixed-term projects that allow funders to monitor progress and adjust conditions if necessary. This raises difficult issues related to eligibility and potential co-funding, particularly in developing countries with a large "adaptation deficit" (Burton, 2004), where there are close links between adaptation to climate change, adaptation to natural climate variability and broader issues of socio-economic development. These links raise two central questions for defining eligible adaptation measures:

1) Is eligible adaptation restricted to measures that reduce the risks of anthropogenic climate change or are measures to reduce the risks of natural climate variability also included?
2) Is eligible adaptation restricted to measures that are motivated primarily by climatic risks or does it also include measures where reduction of such risks is only one of several benefits?

Based on these two questions definitions of adaptation range from very strict (definition 1) to very broad (definition 4) (Table 17-1).

[INSERT TABLE 17-1 HERE
Table 17-1: Four definitions of eligible adaptation.]

A strict definition of eligible adaptation may make it politically easier to motivate the need for international adaptation funding but risks excluding many efficient projects if they are not primarily motivated by climate change. A broader definition makes it easier to find projects that reduce current as well as future climatic risks but it risks losing the focus on adaptation and the associated political momentum for international funding. When a broad definition of adaptation is applied, co-financing by recipient countries may appear justified under certain conditions. The level of co-financing would depend on the relative importance of climate change compared to other reasons for a particular measure and on the resources that a country can reasonably provide itself (Füssel *et al.*, 2012). However, coherent criteria for measuring the fraction of an "adaptation project" attributable to anthropogenic climate change or for determining the level of co-financing requested for projects that address climate change adaptation jointly with other policy goals have not been developed so far. If adaptation funding is restricted to additional adaptation costs and primary funding comes from another external source, close coordination between both funders is required for practical reasons (Agrawala, 2008).

17.2.2.3. International Burden Sharing

Climate change is characterized by a "double inequity" (Stern, 2007) because those countries that are most vulnerable to climate change have generally contributed least (on a per capita basis) to causing it (Panayotou *et al.*, 2002; Tol *et al.*, 2004; Mendelsohn *et al.*, 2006; Patz *et al.*, 2007; SEGCC, 2007; Srinivasan *et al.*, 2008; Füssel, 2010). This asymmetry between responsibility and capability on the one hand and vulnerability on the other is considered unjust based on concepts of justice that include the "no harm" principle and the polluter pays principle. This injustice implies obligations for countries with high responsibility and/or capability, and rights for countries with high vulnerability. The distinctive justice issues raised by international adaptation policy have recently gained a more prominent role in the scientific literature (Adger *et al.*, 2006; Paavola and Adger, 2006; Miller, 2007; Heyward, 2007; Comim, 2008; Jagers and Duus-Otterström, 2008; Mearns and Norton, 2009; Klinsky and Dowlatabadi, 2009; Grasso, 2010; Harris, 2010; Inthorn *et al.*, 2010; Füssel, 2011; Füssel *et al.*, 2012).

The United Nations Framework Convention on Climate Change (UNFCCC) contains various provisions for financial support from industrialized countries to vulnerable developing countries but adaptation became really important in the UNFCCC negotiations only in 2001, when the 7th Conference of the Parties (COP 7) to the UNFCCC established three funds to support adaptation in developing countries. However, the rights and obligations related to adaptation funding were not clearly defined in the UNFCCC, leaving significant room for legal and political debates (Verheyen, 2002, 2005; Klein and Persson, 2008; Dellink *et al.*, 2009; Klein, 2009; Persson *et al.*, 2009; Hof *et al.*, 2010; Füssel *et al.*, 2012).

Important questions that are the subject of controversy in international negotiations on global adaptation funding as well as in academic debates are (Füssel *et al.*, 2012):

- Who pays and how much into the adaptation fund based on which criteria?
- Who is eligible for receiving payments from the fund, and which criteria are used for prioritising recipients and for allocating funds?
- Which adaptation measures are eligible for funding, and what are the conditions and modalities for payment?
- How and by whom are decisions made?

While there is broad agreement that substantial payments are required from industrialized countries to support adaptation in developing countries, none of the questions above can be answered unequivocally based on legal or ethical considerations. Furthermore, these questions are not independent of each other as insufficient availability of funds can give rise to additional conflicts. In particular, efficiency and equality goals can be in conflict with each other if effective adaptation in one country is much more costly through no fault of their own (e.g. due to unfavourable geographical conditions) than in another country and the adaptation fund has insufficient resources to fulfil all justified claims (Füssel, 2011; Füssel *et al.*, 2012).

17.2.3. Adaptation and Mitigation as Competitive or Complementary Investments

Adaptation and mitigation funding may need coordination. AR4 WGII chapter 18 presents a discussion of trade-offs and synergies. Often these are rival choices where investments in one might preclude those in the other. They also compete with consumption and non-climate investments. For example some adaptation strategies require land-use change as do both mitigation strategies and food production. Nevertheless the judicious use of adaptation jointly with mitigation lowers the total cost of climate change and implies a portfolio approach (de Bruin et al, 2009; Wang and McCarl, 2012, Koetse and Rietveld, 2012). Also mitigation reduces the uncertainty and magnitude of future changes in climate, making adaptation cheaper and thus more efficient (Hallegatte et al., 2010).

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 precisely. The U.S. National Academy of Sciences (2010), 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") Others have simply identified residual damages as those that remain after adaptation is implemented (World Bank 2010).

As an illustration of the relationship between adaptation cost and residual damage, Hallegatte *et al* (2011) conducted a study of the consequence for Copenhagen of sea level rise and the costs of adaptation, projecting mean annual losses as a function of the protection provided (see Figure 17-2).

[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.]

De Bruin et al (2009) and Hof et al (2009) have examined how increasing efforts lowers residual damages and formulate a model where adaptation actions are taken to the point that their marginal costs just offset marginal residual damages. Parry et al 2009 introduces unavoidable damages and Wang and McCarl (2012) study them, showing that higher degrees of unavoidable damages merit more mitigation but less adaptation effort.

17.2.5 Defining What Constitutes The Cost of Adaptation

Some define the cost of adaptation as simply the additional investment needed to adapt to future climate change (UNFCCC, 2007). But a full cost accounting needs to consider capital, operating, and nonmonetary costs of adaptation, considering metrics beyond those in monetary units. An economic approach would commonly take one of two definitions: 1) Costs of adaptation are the full range of costs incurred to undertake all appropriate adaptation measures; or 2) Costs of adaptation are the full range of costs incurred to restore economic welfare to pre-climate change levels (World Bank 2010). This would include the costs of fully implementing a given set of adaptation strategies including the opportunity cost of the funds used.

Defining an "adaptation project" and its cost raises conceptual issues. Many actions have an influence on the impact of climate change without being adaptation projects per se (e.g., enhanced building norms). Many "adaptation actions" have consequences beyond a reduction in climate change impacts. Defining the adaptation component (and cost and benefit) of a project requires the definition of a baseline (what would be the impact of climate change in absence of the adaptation action? What alternative project would be implemented in the absence of climate change?), and evaluation of the "additionality" of the project. For instance, action to adapt existing infrastructure to climate change are pure adaptation projects, and their cost can be considered as adaptation costs. The building of new infrastructure may be more costly because of climate and in that case only a fraction of their cost can be attributed to climate change and be labeled adaptation cost (See Dessai and Hulme 2007).

17.2.6. Methodological Considerations

17.2.6.1. Data Quality and Quantity

There is very little discussion on data gaps related to assessing the benefits of adaptation. Callaway (2004) suggests that a major challenge is the low quality and limited nature of data, especially in many developing countries. He also notes many transactions are not reported because they occur in informal economies and social networks. In a more general setting Hughes et al (2010) note that historical weather data is not typically sufficiently detailed while others note sparse data on costs of adaptation actions. For example, Bjarnadottie et al. (2011) note incomplete and contradictory data on house retrofit costs for hurricane protection. Also there are simply missing non market data on such items as recreational fishing as affected by climate and possible adaptation.

17.2.6.2. Costs and Benefits are Location-Specific

Calculating localized impacts requires detailed geographical knowledge of climate change impacts, but these are a major source of uncertainty in climate models (see J. C. Refsgaard & K. Arnbjerg-Nielsen & M. Drews & K. Halsnæs & E. Jeppesen, H. Madsen & A. Markandya & J. E. Olesen & J. R. Porter & J. H. Christensen (2013), The role of uncertainty in climate change adaptation strategies—A Danish water management example Mitig. Adapt. Strateg. Glob Change, 18, 3, 337/359.). 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

It is sometimes assumed that climate will change but society will not (Pielke, 2007; Hallegatte et al 2011; Mechler and Bouwer, 2013). Future development paths affect climate change impact estimate, and can alter estimates from positive to negative impacts or vice versa. Some studies show higher growth rates raise hurricane vulnerability (Bjarnadottir, 2011). On the other hand, higher incomes allow the funding of risk-reducing policies.

17.2.6.4. Discount Rates Matter

Because adaptation costs and consequences occur over time, discount rates are a core question. Opinions vary sharply on this question (Baum, 2009, Beltratti Chichilnisky and Heal XXXX). Hof et al (2010) notes that a low discount rate is needed for distant future climate change to matter. A low discount rate is the primary reason for the relatively high estimates of climate damage in the Stern Review.

For climate adaptation projects, the social discount rate is the relevant one (Heal 2009). The rates used fall between 0.1 and 2.5%, although without good arguments for specific values (see Heal 2009). Nordhaus (2007) chooses a value of 1.5% while Stern uses a much lower value of 0.1%. Nordhaus emphasizes consistency with the rate of return on investment as a driving rationale while Stern points to ethical issues. Allowing environmental services to enter consumption can change the social discount rate substantially and generate a low or even negative social discount rate (Heal (2009), Guesnerie (2004) and Sterner and Persson (2007)). The UK Treasury now mandates the use of declining discount rates for long-term projects, as suggested by behavioral studies and by theoretical analysis (Arrow et al. 2012).

Weitzman (2007) treats differences in discount rates as different independent estimates of a true but unknown discount rate and points out that we should average different discount factors rather than rates, providing a case for a declining discount rate. Heal (2012) suggests that differences in discount rates reflect different value judgments and suggests they be resolved by a social choice procedure, perhaps by choice of the median rate. Wen (in: Bjarnadottir et al (2011)) investigates adaptation sensitivity against multi-hazards under discount rates varying from 0% to 9%. He proposes using a discount rate that decreases over time, as also recommended for longer term appraisals in the Green Book of the UK Treasury (from Hof et al, 2010).

17.2.7. Adaptation, Poverty, Equity, and Development

There is a relationship between adaptation actions and economic development actions, particularly in lesser-developed countries (see chapter 20). Development goals can be consistent with adaption goals, but not always. Many development projects enhance both adaptation and future development. For example, road construction practices that accommodate higher temperatures and more intense rainfall (World Bank 2009); agricultural investments that enhance heat tolerance and drought resilience (Butt et al. 2005, Strzepek et al. 2010); and public health investments that increase climate-enhanced disease resistance (Samet 2009, Markandya and Chiabai 2009). Development in general can make more resources available for adaptation.

A relevant question concerns whether economic development is a form of adaptation. SREX (IPCC, 2012) shows extreme event damages are ten times as large in developing areas as in developed areas and also that sustainable development can be threatened by climate change. Development generally diminishes vulnerability and raises adaptation capability (Schelling 1992, Schelling 1997, Tol 2005). However, development can also lead to increased vulnerability, for instance through urbanization of flood-prone areas (Hanson et al 2011). Furthermore better protection creates increased vulnerability to extreme events or protection failure (Burby 2001. Hallegatte 2012).

17.3. Decisionmaking and Economic Context for Adaptation

This section focuses on aspects of adaptation decisions making, individual interactions, and limits and obstacles to adaptation.

17.3.1. What are the Objectives of Adaptation?

The specific objectives involved in an adaptation effort can be diverse. One may try to cancel all impacts (negative and positive), maintaining the status quo. Alternatively one can try to cancel adverse impacts and capture positive opportunities, so that the welfare gain (or loss) is maximized (or minimized) as in IPCC (2007). These general objectives can be translated into operational rules and indicators for success in many ways.

Part of the literature presents adaptation as a continuous, flexible process, based on learning and adjustments. This branch emphasizes the need to preserve welfare, and opposes the static view of maintaining a status quo (IPCC SREX, Ch 8). Adaptation projects informed by this approach emphasize the role of learning and experimenting, plus the value of 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). Adaptation can also be “transformative’, when achieving existing goals becomes impossible or undesirable, and changing goals becomes necessary (Stafford-Smith et al., 2011). Hunt and Taylor (2009) outline methods that could be used to model changes in future preferences, and provide examples addressing health and cultural heritage. Beltratti, Chichilnisky and Heal (1998) consider option values that arise as a result of uncertainty about future preferences.

17.3.2. Information, Transaction Costs, and Market Barriers

Transaction costs include the costs of accessing markets and information, along with reaching an agreement (Coase, 1937 and 1960; Williamson, 1979) and enforcement costs. Because of transaction costs, a mutually beneficial exchange may be impossible, and some adaptation actions may be impeded.

Certain publicly beneficial adaptation measures may not be privately beneficial due to such costs. Homeowners may not insulate homes due to transaction costs, whereas the collective benefit would be considerable (Hallegatte et al., 2007). This is a “market barrier” that appears even in absence of market failure (Jaffe et al., 2004).

17.3.3. Market Failures and adjustment costs

Adaptation may also face market failures such as externalities and moral hazards. As a consequence, some socially desirable actions may not be privately profitable. For example, construction may proceed in flood-prone areas even though this raises future social costs. In many countries flood plain risks are partly assumed by social insurance, transferring risk to the community (Burby et al., 1991, Laffont 1995). There are also externalities, since one household or firm located in a risky location may create higher social damages, for instance through the impact on supply chain (Tierney, 1997, and Henriet et al., 2012), thus requiring public norms and standards, tax measures or institutions in order to avoid such effects.

Significant (non-marginal) economic shifts and transitions involve significant adjustment cost driven by coordination failures and by factor immobility. There would be no adjustment costs if workers were able to move freely, firms were able to mobilize their fixed capital and technologies, and all economic actors had perfect information on the future. But experience with trade liberalization shows significant adjustment costs. We observe that this creates and destroys jobs in different sectors, but causes only limited intersectoral labor flows. In Brazil workers displaced from de-protected industries were only absorbed by other sectors with a several year lag (Muendler 2010). The same effects will be observed in the process of adapting to climate change.

17.3.4. Behavioral Obstacles to Adaptation

Economic agents adapt continuously to climate conditions, though not always using the available information, especially long-term projections (Camerer and Kunreuther, 1989) and consequences (Thaler, 1999, Michel-Kerjan, 2008). It has been observed for energy efficiency investments that households act in a way consistent with a very high discount rate of 20 to 100% (Train, 1985).

Also, individuals defer choosing between ambiguous choices (Tversky and Shafir 1992; Trope and Lieberman, 2003), a common situation regarding climate change adaptation. They systematically favor the status quo and familiar choices (Johnson and Goldstein, 2003). Also, individuals value profits and losses differently (Tversky and Kahnman 1974). In-depth studies show that these behavioral issues partly explain suboptimal household decisions (Shogren and Taylor, 2008, Gillingham et al., 2009), and lead to patterns of adaptation that are suboptimal.

17.3.5. Ethics and Political Economy

A difficulty in allocating adaptation resources is that there is no obvious choice of performance indicator (Füssel, 2010). Outcomes are often measured using indicators like GDP or cost benefit tests. But their limits are well known, (e.g., CMEPSP, 2009; OECD, 2009, Heal 2012) and include the failure to take into account resource depletion, environmental change, and distributional issues.

Distributional issues justify public intervention. Climate change impacts vary greatly by social group, and many have suggested that the poor are particularly vulnerable (e.g., Stern, 2006; Füssel, 2012). Some individuals, firms, communities and even countries may be unable to afford adaptation, even if it is in their own interest. Consideration of justice and fairness will play a role in adaptation option design (Pelling and Dill, 2009; O'Brien et al., 2009; Dalby 2009; Brauch, 2009a, 2009b; O'Brien et al., 2010b). The implementation of adaptation options may thus require taking into account the political economy of reforms and the addition of complementary policies to compensate losers (World Bank 2012).

Consequently, we must compare measures considering their equity implications. The traditional economic approach suggests choosing the most cost-effective projects and then resorting to financial transfers to satisfy equity objectives (Brown and Heal 1979: Atkinson and Stiglitz, xxxx). However this embodies strong assumptions including the ability to realize perfect and costless financial transfers. In more realistic situations the choice is not so clear cut. And in practical terms transfers are difficult to organize and may not be politically acceptable (Kanbur 2010). For example international development aid is often politically controversial (Bulir and Hamann, 2008). In these cases we have to resort to rankings that reflect both the net benefits and the impacts on equity.

17.3.6. Economic Decisionmaking with Uncertainty

17.3.6.1. Climate Change and Uncertainty

Decisions about adaptation have to be made in the face of uncertainty on items ranging from demography and technology to economic futures. Climate change adds to this with sources of uncertainty including:

- Uncertainty about the extent of future climate change (AR5, WGI report).
- Uncertainty about how climate change will translate into local impacts (AR5, WGI report).
- Uncertainty about the reaction of ecosystems and societies to climate change. An example is the ability of coral reefs to cope with warming.

The combination of uncertainty coupled with the long lifespan of a number of options leads to possible maladaptation. A distinction must be made between two types of maladaptation. An "*avoidable*" maladaptation situation arises from a poor *ex ante choice*. An "*unavoidable*" *ex post* maladaptation can result from entirely appropriate decisions based on the information that was available *at the time*. An example is agricultural irrigation, where current investments to cope with a drying climate deplete water resources, resources that could facilitate later adaptation (Pfeiffer and Lin, 2010).

17.3.6.2. Comparing Adaptation Measures under Uncertainty

Next we consider methods to compare adaptation strategies under uncertainty. The first method is cost-benefit analysis under uncertainty where subjective probabilities are assigned to different climate futures (e.g., Tebaldi et al., 2005; New and Hulme, 2006). The "best" average project then will be the one that maximizes the average net present value of costs and benefits considering the probabilities. Risk aversion can be taken into account by seeking to maximize average income minus a risk-aversion measure times the variation in costs and benefits (or via an expected utility approach). It is also possible to implement a robust decision making approach that focuses largely on the worst possible outcomes, the so-called "maxi-min" approach. The cost-benefit approach also allows attribution of a higher weight to the poorest (Harberger, 1984).

Application of cost-benefit analysis requires evaluations in monetary terms. In many cases this is straightforward although these prices may need to be corrected for policies, monopoly power or other external factors distorting market prices (Squire and van der Tak, 1975). In cases where there are non-market items, a range of non-market valuation approaches (section ***17.3.6.3)*** can be adopted, but results are dependent on local conditions plus ethical and political choices.

When conducting cost-benefit analyses under uncertainty, an important concept is that of decision delay or option value (Henry 1974, Arrow and Fisher 1974). Indeed, when knowledge improves over time, it is possible to delay a decision and wait for more information. A key issue concerns irreversible actions, such as the destruction of a unique environment (Heal and Kristrom (2003)).

All these methods require probabilities for each climate scenario. However, these are difficult to determine, especially for low-probability, high-impact cases (Weitzman 2009, Kunreuther et al. 2012). Climate problems are in the realm of ambiguity rather than risk, meaning that while there is some information about relative likelihoods, this does constitute a probability distribution (Gilboa 2010). There is little work that applies such ideas to climate policy (see Henry and Henry, 2002, Millner et al 2010 and Kunreuther et al 2012). One approach is to work with a variety of physical models and posit probabilities that these models are correct. These alternative models can be thought of as scenarios.

In practice, a set of model scenarios is often the only available information. In this case, a scenario-by-scenario decision approach can be used (Lempert and Schlesinger, 2000; Ranger et al, 2010; Hallegatte et al 2012), looking for policies that are acceptable within a maximum number of scenarios. The aim is not to maximize the benefits within a scenario (or the average scenario) but to remain above the acceptable level for as many scenarios as possible. The most rigorous version of this method is the "maxi-min approach", in which we optimize for the most pessimistic scenario. The disadvantage can be that the most pessimistic hypothesis is highly unlikely.

17.3.6.3. Valuation of Non-Market Costs and Benefits

Cost-benefit analysis (CBA) of adaptation options often requires the valuation of non-market costs and benefits, i.e. the valuation of effects for which no value can be directly observed in a market. This is the case for impacts on public health, cultural heritage, environmental quality and ecosystems. The impacts of climate change on ecosystem services clearly have consequences for human wellbeing, both directly and through their impacts on economic activities. There has been progress in valuation of regulating, provision and cultural ecosystem services , as elaborated in the Millennium Ecosystem Assessment (MEA, 2005), The Economics of Ecosystems and Biodiversity (TEEB 2010) and Bateman et al (2011). There are two main categories of approaches to valuing ecosystem services; revealed and stated preference methods. As time and resources are scares when doing a CBAs we often resort to value transfer techniques (Navrud and Ready 2007). Brander et al (2012) applies value transfer to climate change impacts on wetlands, which would be the benefits side of adaptation measures. For an overview see National Research Council 2004.

17.3.6.4. Examples of Multi-Metrics Decisionmaking for Adaptation

Multi-criteria analysis (MCA) is applicable to non-market impacts when valuation is impossible for theoretical or practical reasons. This approach does not require criteria to be measured in a common metric, but they must be weighted to reflect relative importance. Decision makers can include a full range of social, environmental, technical, and economic criteria—mainly by quantifying and displaying trade-offs. MCA is also useful when there is insufficient data for cost-benefit or cost-effectiveness analysis.

MCA approaches have been applied to adaptation issues including urban flood risk (Grafakos 2011; Kubal et al. 2009), agricultural vulnerability (Julius and Scheraga 2000) and studies on choice of options in the Netherlands (De Bruin et al. 2009; Brouwer and van Ek 2004), Canada (Qin et al. 2008) and Africa (Smith and Lenhart 1996). The UNFCCC developed guidelines for the adaptation assessment process in developing countries in which it suggests the use of multi-criteria analysis (UNFCCC 2002).

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. Ancillary effects also arise when investment funds devoted to mitigation or non-climate related investments in addition increase climate adaptation.

17.4.1. Broad Economic Consideration of Adaptation

In some cases adaptation strategies may be justified without detailed consideration of climate-related benefits because of ancillary benefits (these are sometimes referred to as “no regrets” strategies). Examples include:

- Sea walls that protect against sea level rise and at the same time will protect against tsunamis. However they also have co-costs causing damages to adjacent regions, fisheries and mangroves (Frihy, 2001);
- Crop varieties that are adapted to droughts and heat – will also raise productivity in the absence of climate change (Birthal et al, 2011);
- Better building insulation – which protects against heat will also reduce heating and cooling energy consumption (Sartori and Hestnes, 2007) and mitigate greenhouse gas emissions;
- Public health measures targeted at insect-borne diseases whose range will expand in a warmer world – will also have health benefits at present (Egbendewe-Mondzozo et al, 2011);
- More efficient use of water –adaptation to a drier world- will also yield benefits under current conditions of water scarcity. Development of lower-cost desalination methods have the same merits (Khan et al, 2009);
- Locating infrastructure away from low-lying coastal areas provide adaption to sea level rise and will also protection against tsunamis and storm surges;
- Afforestation and reforestation may improve adaptation of land production and will also both mitigate by carbon sequestration and benefit society 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 will also provide mitigation , improve air quality and reduce health impacts (Burtraw et al, 2003).

17.4.2. Economic Consideration of Ancillary Effects

Suppose that a country has a fixed sum of money to allocate between two competing adaptation projects, each showing diminishing returns. To maximize benefits the funds should be allocated so that the marginal returns to each activity are the same. If both strategies generate positive ancillary effects not captured by the actor undertaking the adaptation, then the socially optimal allocation of adaptation investment will differ from the private optimum and will favor the activity with the larger ancillary effects. Elbakidze and McCarl (2007) argue that it may be best to disregard ancillary effects because of the complexity of a complete analysis and the fact that in the settings they examine ancillary effects are roughly of the same magnitude. Viguie and Hallegatte (2011), Kubal et al. (2009), De Bruin et al. (2009), Brouwer and van Ek (2004), Ebi and Burton (2008), Qin et al. (2008), among others argue the contrary.

Equally important, and more difficult, is determining how much should be spent in total on adaptation versus other investments – mitigation, other aspects of development. For the best possible outcome the marginal social returns to all forms of expenditure should be the same, if appropriate, allowing for distributional impacts by differentially weighting benefits and costs to different income groups (Brent, 1996; Musgrave and Musgrave, 1973). In practice governments try to achieve this by setting a target rate of return for all 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)

17.4.3. Adaptation and Development Pathways

Adaptation is often considered on a project by project basis. In this "stand-alone" framework, adaptation actions are additional policies, and they are not included in other policies, such as development or economic policy. This is for instance the approach followed by the "National Adaptation Programmes of Action" of the UNFCCC (2002). Another vision is considering adaptation as an additional objective of development, which influences development policies (Klein et al. 2005; Füssel, 2007; Kok and De Coninck, 2007; O'Brien et al., 2012). This broader 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. It is consistent with other trends in environmental policies that integrate risk management policies within development policies (Kellenberg and Mobarak, 2008; UN-ISDR 2009; World Bank and UN 2011), and climate mitigation polices now approached more as a low-carbon development issue than as a purely environmental issue (Stern, 2006; World Bank 2010).

17.5. Economic and Related 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 public private partnerships (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

Insurance-related mechanisms can directly lead to adaptation and provide incentives or disincentives, which may involve formal and informal mechanisms. Informal mechanisms include reliance on national or international aid or remittances, and while such mechanisms are common, they tend to break down for large, covariate events (Cohen and Sebstad, 2003). Another informal mechanism is the inclusion of climate change risk under corporate disclosure regulations (National Round Table on the Environment and the Economy, 2012). Formal mechanisms include insurance (including micro-insurance), reinsurance, and national, regional and global risk pooling arrangements. Insurance typically involves ongoing premium payments to an insurer / reinsurer or the financial markets in exchange for coverage and post event claim payments (UNISDR, 2009). 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 penetration in developed countries is considerable, whereas it is low in many developing regions (Linnerooth-Bayer et al., 2011). In 2010 globally about 30% of disaster losses and 20% of climate related losses were insured.

Insurance-related instruments may directly and indirectly lead to adaptation. Two direct channels can be distinguished: i) instruments provide claim payments after an event, and thus reduce follow-on risk and consequences; (ii) they alleviate certain pre-event risks and allow for improved decisions (Skees et al., 2008; Hess and Syroka, 2005; Hoeppe and Gurenko, 2006). As one interesting example, using crop micro insurance linked to loans, farmers exposed to severe drought in Malawi were able to grow higher-yield, yet higher-risk crops, which allowed them to increase incomes (Linnerooth-Bayer and Mechler, 2011).

Indirect effects also exist. Premiums for risk coverage can provide an incentive to reduce the premium by reducing the risk. For example, differential UK flood insurance premium pricing offered according to flood zones has been effective in deterring new construction in high risk areas (Kunreuther and Michel-Kerjan, 2009; Kunreuther) and the National Flood Insurance program (NFIP) in the US requires communities to reduce risks before homeowners can access insurance for their homes (Surminski, 2010)

Developing countries are beginning to pool risks and transfer portions to international reinsurance markets. The Caribbean Catastrophic Risk Insurance Facility (CCRIF) set the precedent by pooling risks basin wide, thus reducing insurance premiums against hurricane and earthquake risks (World Bank, 2007). Similar schemes are under development and planning in Europe, Africa and the Pacific (Linerooth-Beyer and Mechler 2011).

The incentive effect is typically rather weak since decisions regarding risk prevention and adaptation are often influenced by many diverse factors. Kunreuther et al. (2009) found that insurance decisions are not based solely on costs and premiums, but also desires to reduce anxiety, comply with mortgage requirements, and satisfy social norms. Further, purchasing insurance may reduce adaptation with insured agents reducing their risk-minimizing efforts after taking out coverage. This is termed moral hazard and has been found to be rational for agents given the financial security provided by the contract (Kunreuther, 1996). Ultimately, this may increase maladaptation over time (Rao and Hess, 2009). Under-insurance can also arise when agents expect that the public sector will provide disaster assistance. Some refer to this as the Samaritan’s dilemma (IMF, 2008).

17.5.2. Incentive Design

Through regulations, subsidies and direct intervention, there are many opportunities for policy makers to encourage autonomous adaptive responses to climate change. However, these efforts need to be designed so that they lead to efficient, cost effective responses while avoiding perverse results that run counter to the policy maker’s objectives. A basic principle of designing efficient policies is that they affect the behavior of those who have the most to gain. For this reason, economists tend to favor policies based on voluntary actions influenced by incentives, either positive or negative, over mandates or uniform policies. Examples of these include water markets and various Payments for Environmental Services (PES), which are discussed in 17.5.4. A second consideration is cost effectiveness, 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.

Finally, policies must be carefully designed to avoid perverse outcomes that actually run 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. Pfeiffer and Lin (2010) review cases where subsidizing irrigation water conservation actually leads farmers to increase total water use as they respond to greater efficiency by increasing the acreage under irrigation, an example of what is often called the rebound effect (Roy, 2000) whereby increases in efficiency of resource use result in more 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 long been involved in the provision of public goods through Public Private Partnerships (PPPs). 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, public loan guarantees and concessional loans (Bräuninger et al. 2011). PPPs have been widely used for large infrastructure projects, one relevant example being the Thames flood defence barrier which protects London and the Thames estuary from tidal surges and coastal flooding. Finance was generated entirely by taxpayers, yet design, building supervision and construction were outsourced to the private sector (Bräuninger et al. 2011).

17.5.4. Payments for Environmental Services

Environmental services (ES) can contribute to adaptation (Millennium Ecosystem Assessment (2005), Daily (1997) and Heal (2000)). Payments for environmental services (PES) are a popular market-based approach that has been applied increasingly to translate external, non-market environmental services into financial incentives for preservation (Wunder et al, 2008; Wünscher et al, 2008; Engel et al, 2008). Those who stand to lose from decisions resulting in ES loss could choose to provide incentives for decision makers to adopt practices that ensure the continuation of the ES (Engel et al., 2008).

PES approaches in developing countries 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. However it has been found that structuring the schemes is difficult when the services are hard to define (such as biodiversity) and where the scheme is driven more by government objectives and less by local needs. In such cases payments often do not guarantee the environmental improvements in spite of large outlays.

There are ample cases of mitigation–focused PES schemes (e.g. Wunder and Borner (2011), Pagiola (2008), Wunder and Albán (2008)), and more recently emerging evidence of the use of PES adaptation approaches. (Butzengeiger_Geyer et al., 2011; Schultz, 2012). Potentially well designed PES schemes they offer a framework for adaptation. Chishakwe *et al* (2011) draw comparisons and find synergies between PES community based natural resources management approaches in Southern Africa and community-based adaptation.

17.5.5. Improved Resource Pricing (Water Markets)

Studies of water sector adaptation 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 is the establishment of water markets and pricing schemes (e.g., Alavian et al. 2009; Vorosmarty et al. 2000, Adler, 2009). Traditionally water markets facilitate transfer from lower to higher-valued uses (Olmstead, 2010). A few studies make the case that water markets and pricing lower the impacts of climate change (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 water supply, suggests that water supply/demand adaptation can only be achieved by a choice between water rationing and water pricing.

Many countries have instituted structures for water pricing in the domestic and agricultural sectors. 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 (Saleth et al.,2012). In a number of countries, there remain a number of important institutional barriers to water markets and pricing. 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).

17.5.6. Charges and Subsidies including Land Taxes

The environmental economics literature over the past 30 years has emphasized the importance of market-based instruments (MBIs) relative to command and control regulations. MBIs are shown to be generally more cost effective, providing stronger incentives for innovation and dynamic efficiency. Within the wide range of instruments that qualify as market based, there is a general preference in terms of overall efficiency for axes over subsidies (Sterner, 2002; Barbier and Markandya, 2012).
In many cases climate change exacerbates 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 like water, genetic materials, pollination, erosion control and soil retention. If these resources were better priced, the need for additional public sector adaptation measures would 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 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.

17.5.7. 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 differently react to abstract information on distant events, versus 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 well documented that individuals do not use available information on natural risks when they make their choices (Magat et al., 1987; Camerer and Kunreuther, 1989; and Hogarth and Kunreuther, 1995). 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, using specific examples and real-world stories. Moreover, people usually overreact in the aftermath of a rare event (Weber et al. 2004), leading to biased and under-optimal responses (Hallegatte, 2011).

17.5.8. Intellectual Property Rights

Technology transfer is increasingly seen as an important means of adaptation. Christensen et al. (2011) in a Technology Needs Assessments carried out in developing countries list about 165 technological needs. In many of these cases patents and other intellectual property protection constrain technology transfer. Patent buy-outs, patent pools, compulsory licenses and other open source approaches have been used to relax this constraint (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 in a developing country. 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). Compulsory licenses are issued by governments and allow patent rights to be overridden in critical situations. It is suggested that limits to technology transfer are limiting climate change adaptation (Henry and Stiglitz, 2010).

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.

17.5.9. Innovation, R&D Subsidies

Subsidies may be employed to encourage adaptation investments as well as behavioural change (Bräuninger at al., 2011). Subsidies involve direct payments, tax reductions or price supports that enhance the rewards from the implementation of an activity (Gupta et al., 2007). There has been some criticism of the efficiency of subsidies in terms of rent seeking and adverse effects on competitiveness (Barbier and Markandya, 2012); yet they are popular with decision-makers and the wider public. Subsidies are today mostly used for reasons other than climate adaptation, and evidence regarding its use for adaptation as well as regarding the incentivizing of adaptation R&D specifically is missing.

17.6. Costing Adaptation

Interest in estimating the costs of adaptation has grown as the need for action has become clearer. The literature focuses on two levels of costing: 1. global scale estimates, largely to assess the overall need for adaptation finance funds; and regional and local-scale estimates, often limited to a particular vulnerable economic sector, which may be applied to inform budgeting or to support adaptation decision-making, or to allocate scarce resources among the best prospects for effective adaptation.

17.6.1. Review of Existing Global Estimates: 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. The most recent global adaptation costs range from $75 to more than $100 billion annually by 2050 (Table 17-2).

[INSERT TABLE 17-2 HERE
Table 17-2: Estimates of global costs of adaptation.]

IPCC (2012) considers confidence in these numbers to be *low*. The World Bank (2006) estimates the cost of climate proofing foreign direct investments (FDI), gross domestic investments (GDI) and Official Development Assistance (ODA), as does the Stern Review (2006), Oxfam (2007) and UNDP (2007). UNFCCC (2007) calculated existing and planned investment and financial flows required for adaptation. The World Bank (2010a) followed the UNFCCC (2007) methodology but included more extensive modeling as opposed to developing unit cost estimates, constructing marginal cost curves and climate stressor-response functions for adaptation actions, and included maintenance and coastal port upgrading costs.

Given their common approaches these estimates are interlinked, which explains the seeming convergence of their estimates, as discussed by Parry et al (2009). However there are important differences in terms of sectoral estimates, as Figure 17-3 shows in comparing the UNFCCC (2007) and World Bank (2010) studies. Extreme events, a potential source of large adaptation costs, are not covered by UNFCCC (2007), but are partially covered in the World Bank (2010) study and take into account a limited set of adaptation options. Parry et al. (2009) consider the UNFCCC (2007) estimates a significant underestimation by at least a factor of two to three plus omitted costs in ecosystem services, energy, manufacturing, retailing and tourism. They argue these estimates are low, 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. There are a number of gaps, challenges and omissions associated with those global estimates that merit further discussion.

[INSERT FIGURE 17-3 HERE
Figure 17-3: Comparison of sectoral results on the costs of adaptation in developing countries across the UNFCCC and World Bank studies. Note: Bars indicate estimates using ranges, crosses point estimates.]

The practical challenges of conducting global adaptation cost studies are apparent in the literature. The broad scope of these studies limits the analysis to few climate scenarios, and while the scenarios might be strategically chosen it is difficult to fully represent the range of future adaptation costs across all sectors. The broad scope also limits comprehensive consideration of adaptation options, non-market and co-benefits, equity issues, and adaptation decision-making (such limitations also apply to local and regional scale studies see Section 17.6.3). The global studies, designed to reflect the best available methods and data for the purpose of estimating the magnitude of the global economic adaptation challenge, achieve this limited goal but must be interpreted in light of these important limitations and uncertainties.

17.6.2. Consistency between Localized and Global Analysis

Adaptation costs and benefits are derived to inform specific investment decisions, generally at national and local levels, or to derive a "price tag" for overall funding needs for adaptation (generally at a global level). Given these different purposes it is difficult to compare "local", i.e, national and sectoral, with global numbers. The quantity/quality of local studies also varies by sector with more treatment of adaptation in coastal zones and agriculture. Less is known and many gaps remain for sectors such as water resources, energy, ecosystems, infrastructure, tourism and public health. Also assessments have predominantly been conducted in a developed country context (see Table 17-3 for examples of costs and benefits assessment).

[INSERT TABLE 17-3 HERE
Table 17-3: 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 locally or in terms of sectoral to global costs. Fankhauser suggests that the global cost estimates using the I&FF methodology estimate the "true" costs of adaptation. The World Bank (2010) study uniquely takes a two-track approach doing parallel national (7 cases) and global adaptation estimates. For a number of country studies (Bangladesh, Samoa and Vietnam) a cross-country comparison of local and global adaptation costs was made, with the costs in terms of GDP found to be in reasonable agreement. Costs for strengthening infrastructure against windstorms, precipitation and flooding were about 10-20% higher compared to disaggregated global estimates, largely owing to the ability of country-level studies to consider at least some socially contingent impacts (World Bank 2010b, 2010c, 2010d). Further, there is evidence of under investment in adaptation with global estimates of the need for agricultural adaptation funds variously estimated in the range of $10-40 billion annually, but with actual expenditures in 2011 estimated at $244 million (Elbehri et al, 2011)

17.6.3. Selected Studies on Sectors or Regions

Now let us address studies that focus on costs and benefits of specific adaptation strategies. This section focuses on studies that illustrate the current state-of-the-art, with a particular focus on support of adaptation decision-making through economic analysis. 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 past 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., Schlenker 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 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 (Dinar and Mendelsohn, 2011; Schlenker et al, 2005). 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.

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.

Simulation modeling can be demanding – a key disadvantage – as it requires extensive data inputs and careful calibration. It is often not appropriate where data are sparse, and requires that models be available for the task. The payoff is that the modeling system can estimate the incremental change in crop output and water supply in response to changes in climatic conditions and agricultural and water resource management techniques. A further advantage of the simulation approach is that it provides an opportunity for stakeholder involvement at several stages of the analytic process: designing scope, adjusting parameters, selecting inputs, calibrating results, and incorporating adaptation measures of specific local interest (Dinar and Mendelsohn, 2011).

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. Such an approach implicitly acknowledges that planners have a choice along a broad continuum concerning whether to invest in adaptation or tolerate impacts and/or residual impacts. 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.

There are a wide range of studies available that attempt an economic evaluation of adaptation options. From these, several desirable characteristics can be identified. Namely such studies should contain:

- A broad representation of climate stressors, including both gradual change and extreme events, spanning multiple future outcomes((GCM) forecasts and greenhouse gas emissions scenarios). Consideration of multiple outcomes reflects forecasting uncertainty and can help to ensure the adaptation rankings that result are robust across a range of future outcomes (Lempert and Kalra 2009, also see Chapter 2).
- Representation of a wide variety of alternative adaptation responses (for example, in the agriculture sector, consideration of changes in crop varieties and farmer education to ensure the varieties are grown with the best available know-how). Depending on the context, single adaptation response with variation in dimension may be useful (for example, varying the height of a levee or the capacity of a dam spillway) (World Bank 2010, Fankhauser 2010, Fankhauser et al. 1999).

- Rigorous economic analysis of costs and benefits, which ideally includes consideration of market, nonmarket, and socially contingent implications; one-time and replacement capital and ongoing recurring costs; and costs of residual damages after an adaptation response is implemented (Watkiss 2011b).
- A strong focus on adaptation decision making, including a clear exposition of the form of adaptation decision-making that is implied in the study, and consideration of both climate and non-climate sources of uncertainty (Lempert et al. 2006, also see Chapter 2).

Table 17-4 highlights a select group of studies chosen to illustrate some of these characteristics. The studies include both simulation studies of the economic implications of adaptation options, and econometric ones which examine choices that producers make to adapt. These studies generally fall in the category of positive economics, where economic tools and analysis are used to examine the implications of alternative choices without imposing values of the author (see Friedman (1953)). A few studies incorporate a normative perspective, either explicitly or implicitly, reflecting value judgments of authors or study participants.

[INSERT TABLE 17-4 HERE
Table 17-4: Studies illustrating economic evaluation of adaptation options.]

Frequently Asked Questions

FAQ 17.1: Given the significant uncertainty about the effects of adaptation measures, can economics contribute much 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 such as decisions on which coastal areas to protect and how much to protect them.

There are different methods that can be applied, 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 maximizes the expected net benefits allowing for the risks associated with different options. Such an approach compares not only the net benefits of each measure but also the risks associated with it (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 a least cost solution that keeps probable losses to an acceptable level.

In situations where probabilities cannot be defined the analyst can define scenarios that describe a possible set of outcomes for each adaptation measure. In such cases economic tools have been developed that search for solutions which 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, providing "acceptability" can be defined. Applications in the literature can be found for sea level rise, river flooding and energy planning.

There are, however, still unanswered questions on how to apply these methods (particularly when the changes caused by climate change are non-marginal and when preferences change), and how to improve the quality of information on the possible impacts and benefits.

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

An economic approach, which focuses on the costs and benefits of an action is an important component of the final decision on which action to take, given the limited resources available for addressing adaptation. A narrow economic approach can bias decisions against the poor, vulnerable and ecosystems whose value systems are often not captured, or are understated by market prices. For example, the market value of timber does not reflect the ecological and hydrological functions of trees as well as the value of non-marked non-timber forest products like medicines. But the final decision is not based on just this information. Account is also taken of who gains and who 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. Economic data feeds into a broader decision-making framework as one of several considerations. What is crucial is that the overall decision-framework is broad, with both economic and non-economic factors being taken into consideration.

A frequently used decision-making framework that provides for the inclusion of economic and non-economic indicators to measure the impacts of a policy or measure, including impacts on vulnerable groups and ecosystems is multi-criteria analysis (MCA). An issue that remains problematic with methods such as MCA is what weights (including equity weights) to attach to the different criteria.

Alternatively one can 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.

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 are useful in a number of ways. First they help to ensure that the starting point for any adaptation policy involves an efficient use of the resources that will be affected by climate change: water pricing is an example of an EI. If water is already priced properly, there will be less overuse that has to be corrected through adaptation measures when supplies become scarcer. Second, they can function as a flexible, low-cost tool for adaptation. With the same example, if climate impacts result in increasing water scarcity it is easier to adjust the water tariff and less costly than finding new ways of increasing supply.

Insurance is another economic instrument that serves as a flexible, low cost adaptation tool. Where risks can be well defined insurance markets can help reduce vulnerability and also generate funds for post disaster recovery.

Payments for environmental services (PES) schemes are evolving voluntary market based economic instruments used in countries such as Costa Rica to manage natural resources, and can be applied to adaptation. In developed countries, where markets function reasonably well, EIs can be directly deployed through market mechanisms. In many developing countries, this is not always the case and markets often need public action and support. The insurance markets for example, do not cover all risks and there are issues of affordability, which mean that public-private partnerships are often required. The public sector also has an 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 function well when the public sector ensures that rights are defined and agreements honored.

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Table 17-1: Four definitions of eligible adaptation.

Relevant climatic factors **Motivation for action**	**Observed and/or projected climate change**	**Climate change as well as natural climate variability**
Climate is the main reason	**Definition 1:** Action occurs mainly to reduce the risks of observed or projected climate change **Example:** Raising of existing dykes	**Definition 2:** Action occurs mainly to reduce risks of climate change and climate variability **Example:** Building of new dykes in areas that are currently unprotected
Climate is one of several reasons	**Definition 3:** Actions that reduce the risks of observed or projected climate change even if they are also justified in the absence of climate change **Example:** Economic diversification in predominantly agricultural regions	**Definition 4:** Actions that reduce the risks of climate change and climate variability even if they are also justified in the absence of climate change **Example:** Improved public health services

Source: (Füssel *et al*., 2012)*, adapted from* (Hallegatte, 2008)

Table 17-2: 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 17-3: 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 17-4: Studies illustrating economic evaluation of adaptation options.

Sector, Study, and Scope	Methodology	Key Points Illustrated
Agriculture, Forestry, and Livestock		
Seo and coinvestigators (e.g. Seo et al , 2008, 2009, 2011): Impacts to livestock producers in Africa	Econometric. Examines the economic choices that livestock owners make to maintain production in the face of climate Insights into adaption possibilities by examining the ways economic choices vary over locations and times with varying climate conditions.	Consideration of multiple options (implicit) Residual impacts reflected Applicable at multiple geographic scales Results provide a ready means to re-estimate results for multiple climate scenarios.
Butt and McCarl (2006): Crop sector in Mali	Simulation. Simulates the economic implications of potential adaptation possibilities. Examines the consequences of migration in cropping patterns, development of heat resistant cultivars, reduction in soil productivity loss, cropland expansion, and changes in trade patterns.	Broad consideration of options (explicit, allowing for ranking of measures) Residual impacts reflected Rigorous economic costing of adaptation options and consequences for yields, revenue, and food security.
Sutton et al (2013): Crop and livestock sector in four Eastern European and Central Asian countries	Simulation with benefit-cost analysis. Ranks options initially based on net economic benefits over 2010 to 2050 period. Considers non-market and socially contingent effects through stakeholder consultation process.	Broad consideration of options (explicit, measures ranked) Very broad representation of climate scenarios (56 GCM-SRES combinations) Rigorous economic costing of adaptation options Integrated analysis of agriculture and irrigation water sectors
Sea-level Rise and Coastal Systems		
Nichols and Tol (2006):Coastal regions at a global scale	Simulation of adaptation through construction of seawalls and levees, adoption of beach nourishment to maintain recreational value, and migration of coastal dwellers from vulnerable areas. The study, reflects an economic decision-rule for most categories and benefit-cost analysis for a few categories	Capable of broad representation of sea-level rise scenarios. Optimization of alternatives considering both the impact of adaptation and resulting residual impacts. Rigorous economic costing of adaptation options.
Neumann et al. (2010a): Risks of sea-level rise for a portion of the coastal United States	Simulation of adaptation decision-making including seawalls, bulkheads, elevation of structures, beach nourishment, and strategic retreat, primarily using a benefit-cost framework but with alternatives based on local land-use decision-making rules.`	Capable of broad representation of sea-level rise scenarios Flexibility to consider both benefit-cost and rule-based decision making Rigorous and dynamic economic costing of adaptation options
Purvis et al. (2008): Risks of coastal flooding in Somerset, England	What is adaptation strategy here Simulation using a probabilistic representation to characterize uncertainty in future sea-level rise and, potentially, other factors that could affect coastal land-use planning and development investment decisions	Considers the impact of both gradual climate change (sea-level rise) and extreme events (the 1 in 200 year recurrence interval coastal flooding event). Incorporates probabilistic uncertainty analysis
Energy		
Margulis (2011): Energy production in Brazil, particularly from hydropower	Simulation of multiple adaptation options, including energy source substitution and regional “wheeling” of power coupled with modeling of river flow and hydropower production under future climatic conditions. Uses an optimization model of overall energy production	Considers multiple GHG emissions scenarios and a “no-climate change” baseline Scalable to multiple spatial resolutions, with national and regional results reported Considers multiple adaptation strategies Rigorous economic costing of capital and recurring adaptation costs
Health		
Ebi (2008): Global adaptation costs of treatment of diarrhoeal diseases, malnutrition, and malaria	What is the adaptation considered The costs of three diseases estimated in 2030 for three climate scenarios using (1) the current numbers of cases; (2) the projected relative risks of these diseases in 2030; and (3) current treatment costs. The analysis assumed that the costs of treatment would remain constant. There was limited consideration of socioeconomic development.	Multiple climate scenarios Clear description of framework and key assumptions Rigorous economic costing of adaptation options using multiple assumptions to characterize uncertainty

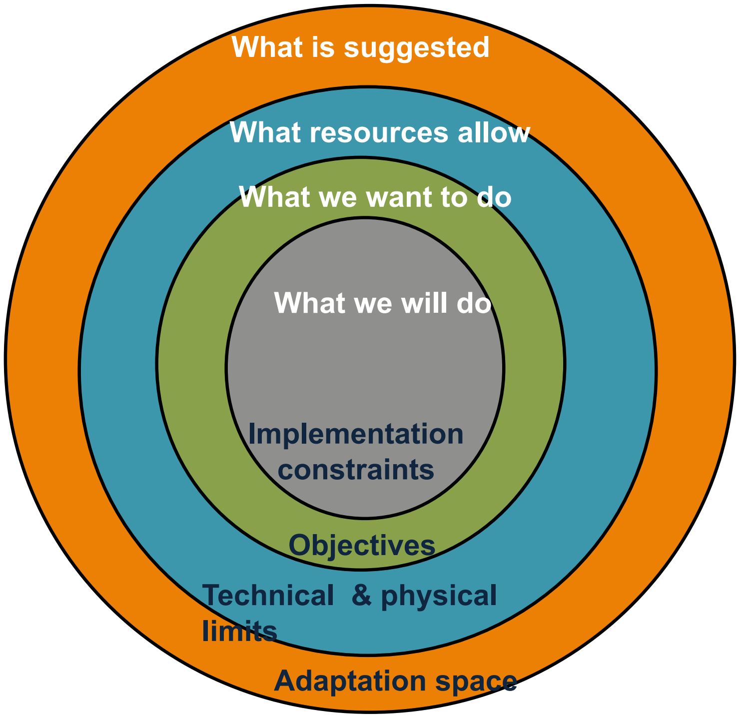

Figure 17-1: The narrowing of adaptation from suggested adaptations to what will be done. Forces causing the narrowing are listed in black.

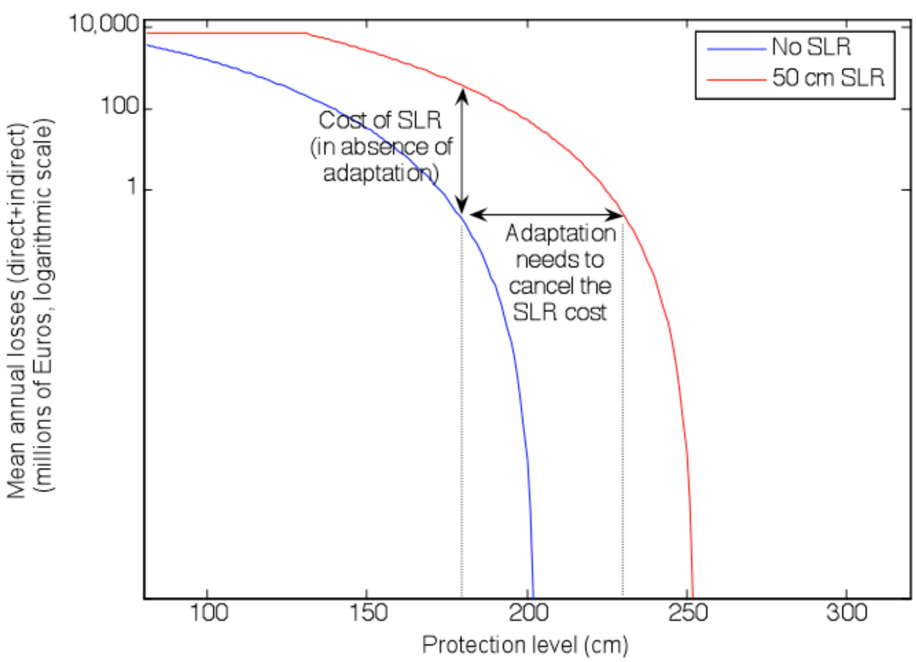

Figure 17-2. Illustrative example assuming a homogenous protection at 180 cm above current mean sea level (in the 'No SLR' and '50 cm SLR' cases). The vertical arrow shows the cost of SLR in the absence of adaptation. The horizontal arrow shows the need for adaptation to maintain unchanged mean annual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

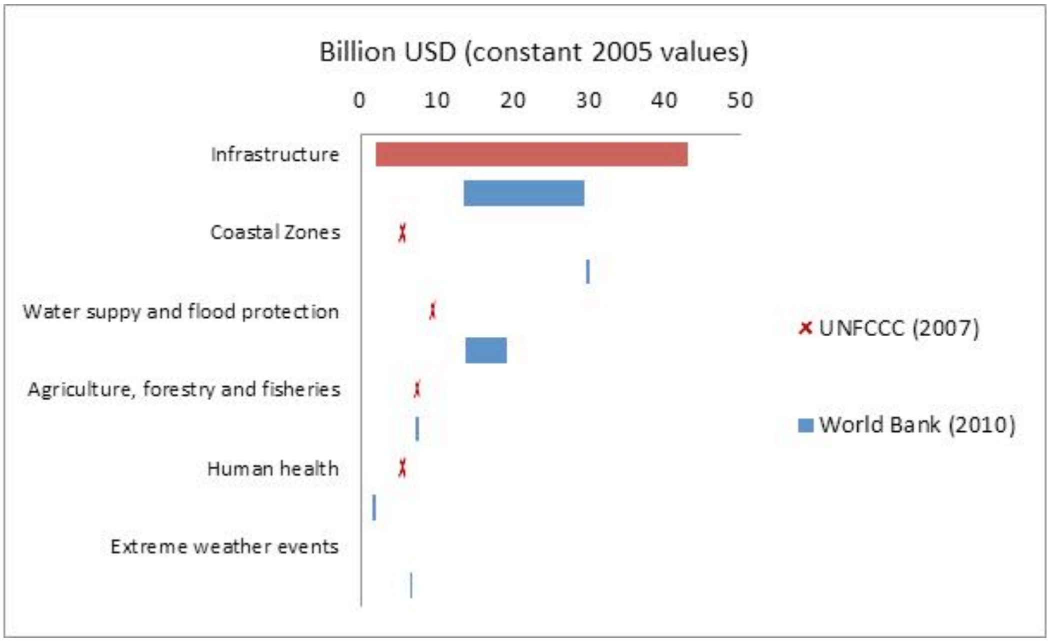

Figure 17-3: Comparison of sectoral results on the costs of adaptation in developing countries across the UNFCCC and World Bank studies. Note: Bars indicate estimates using ranges, crosses point estimates.