18 Understanding the Economics of Adaptation

Key Messages

Adaptation is crucial to deal with the unavoidable impacts of climate change to which the world is already committed. It will be especially important in developing countries that will be hit hardest and soonest by climate change.

Adaptation can mute the impacts, but cannot by itself solve the problem of climate change. Adaptation will be important to limit the negative impacts of climate change. However, even with adaptation there will be residual costs. For example, if farmers switch to more climate resistant but lower yielding crops.

There are limits to what adaptation can achieve. As the magnitude and speed of unabated climate change increase, the relative effectiveness of adaptation will diminish. In natural systems, there are clear limits to the speed with which species and ecosystems can migrate or adjust. For human societies, there are also limits – for example, if sea level rise leaves some nation states uninhabitable.

Without strong and early mitigation, the physical limits to – and costs of – adaptation will grow rapidly. This will be especially so in developing countries, and underlines the need to press ahead with mitigation.

Adaptation will in most cases provide local benefits, realised without long lag times, in contrast to mitigation. Therefore some adaptation will occur autonomously, as individuals respond to market or environmental changes. Much will take place at the local level. Autonomous adaptation may also prove very costly for the poorest in society.

But adaptation is complex and many constraints have to be overcome. Governments have a role to play in making adaptation happen, starting now, providing both policy guidelines and economic and institutional support to the private sector and civil society. Other aspects of adaptation, such as major infrastructure decisions, will require greater foresight and planning, while some, such as knowledge and technology, will be of global benefit.

Studies in climate-sensitive sectors point to many adaptation options that will provide benefits in excess of cost. But quantitative information on the costs and benefits of economy-wide adaptation is currently limited.

Adaptation will be a key response to reduce vulnerability to climate change. Part II highlighted the significant impacts of climate change around the world. The Earth has already warmed by 0.7°C since around 1900. Even if all emissions stopped tomorrow, the Earth will warm by a further 0.5 - 1°C over coming decades due to the considerable inertia in the climate system. On current trends, global temperatures could rise by 2 - 3°C within the next fifty years or so, with several degrees more warming by the end of the century if emissions continue to grow.

But adaptation is not an easy or cost-free option. This Chapter outlines key adaptation concepts and sets out an economic framework for adaptation. It highlights that adaptation is unlikely to reduce the net costs of climate change to zero – namely there will be limits. There will be often residual damages from climate change and adaptation itself will bring costs. The final part of the chapter outlines why policies may be required to overcome barriers and constraints to adaptation in anticipation of future impacts. These policy responses are outlined in more detail in Chapters 19 and 20 for developed and developing countries, respectively.

But even with a policy framework in place, there will be limits to or sharply rising costs of adaptation – for the most vulnerable at moderate levels of warming (e.g. ecosystems, the poorest regions), and for all parts of the world with higher amounts of climate change (4 or 5°C of warming). Developing countries are especially vulnerable to the negative effects of climate change. They are geographically vulnerable, located where climate change is likely to have often damaging impacts, and – as explained in Chapter 20 – are likely to have the least capacity to adapt. Chapter 26 in Part VI picks up this story and outlines how the international community can help developing countries deal with these impacts.

18.1 Role of adaptation

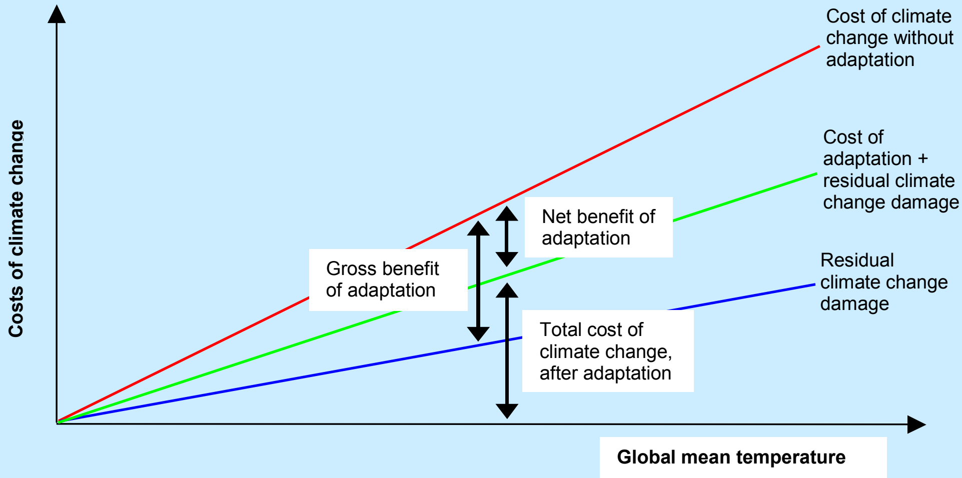
Adaptation is a vital part of a response to the challenge of climate change. It is the only way to deal with the unavoidable impacts of climate change to which the world is already committed, and additionally offers an opportunity to adjust economic activity in vulnerable sectors and support sustainable development.

A broad definition of adaptation, following the IPCC, is any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.[1] The objective of **adaptation** is to reduce vulnerability to climatic change and variability, thereby reducing their negative impacts (Figure 18.1). It should also enhance the capability to capture any benefits of climate change. Hence adaptation, together with mitigation, is an important response strategy. Without early and strong mitigation, the costs of adaptation will rise, and countries' and individuals' ability to adapt effectively will be constrained.

Figure 18.1 The role of adaptation in reducing climate change damages

Adaptation will reduce the negative impacts of climate change (and increase the positive impacts), but there will almost always be residual damage, often very large. The gross benefit of adaptation is the damage avoided. The net benefit of adaptation is the damage avoided, less the cost of adaptation.

The residual cost of climate damage plus the cost of adaptation is the cost of climate change, after adaptation.



For the sake of simplicity, the relationships between rising temperatures and the different costs of climate change/adaptation are shown as linear. In reality, Part II and Chapter 13 demonstrated that the costs of climate change are likely to accelerate with increasing temperature, while the net benefit of adaptation is likely to fall relative to the cost of climate change.

Adaptation can operate at two broad levels:[2]

- **Building adaptive capacity** – creating the information and conditions (regulatory, institutional, managerial) that are needed to support adaptation. Measures to build adaptive capacity range from understanding the potential impacts of climate change, and the options for adaptation (i.e. undertaking impact studies and identifying vulnerabilities), to piloting specific actions and accumulating the resources necessary to implement actions.
- **Delivering adaptation actions** – taking steps that will help to reduce vulnerability to climate risks or to exploit opportunities. Examples include: planting different crops and altering the timing of

[1] Intergovernmental Panel on Climate Change (IPCC) (2001), Chapter 18
[2] UKCIP (2005) Measuring progress, Chapter 4

crop planting; and investing in physical infrastructure to protect against specific climate risks, such as flood defences or new reservoirs.

18.2 Adaptation perspectives

Some adaptation will occur autonomously, as individuals respond to changes in the physical, market or other circumstances in which they find themselves. Other aspects will require greater foresight and planning, e.g. major infrastructure decisions.

Adaptation is different from mitigation because: (i) it will in most cases provide local benefits, and (ii) these benefits will typically be realised without long lag times. As such, many actions will be taken 'naturally' by private actors such as individuals, households and businesses in response to actual or expected climate change, without the active intervention of policy. This is known as 'autonomous' adaptation.

In contrast, policy-driven adaptation can be defined as the result of a deliberate policy decision.[3] Autonomous adaptation is undertaken in the main by the private sector (and in unmanaged natural ecosystems), while policy-driven adaptation is associated with public agencies (Table 18.1) - either in that they set policies to encourage and inform adaptation or they take direct action themselves, such as public investment. There are likely to be exceptions to this broad-brush rule, but it is useful in identifying the role of policy. *The extent to which society can rely on autonomous adaptation to reduce the costs of climate change essentially defines the need for further policy*. Costs may be lower in some cases if action is planned and coordinated, such as a single water-harvesting reservoir for a whole river catchment rather than only relying on individual household water harvesting. The primary barriers to autonomous adaptation will be discussed in Section 18.5.

Table 18.1 Examples of adaptation in practice

Type of response to climate change	Autonomous	Policy-driven
Short-run	▪ Making short-run adjustments, e.g. changing crop planting dates ▪ Spreading the loss, e.g. pooling risk through insurance	▪ Developing greater understanding of climate risks, e.g. researching risks and carrying out a vulnerability assessment ▪ Improving emergency response, e.g. early-warning systems
Long-run	▪ Investing in climate resilience if future effects relatively well understood and benefits easy to capture fully, e.g. localised irrigation on farms	▪ Investing to create or modify major infrastructure, e.g. larger reservoir storage, increased drainage capacity, higher sea-walls ▪ Avoiding the impacts, e.g. land use planning to restrict development in floodplains or in areas of increasing aridity.

The distinction between short-run and long-run adaptation is linked to the appropriate pace and flexibility of adaptation options (Box 18.1). In the short run, the decision maker's response to climate change and variability is constrained by a fixed capital stock (e.g. physical infrastructure), so that the principal options available are restricted to variable inputs to production. For example, a farmer can switch crops and postpone or bring forward planting dates in response to forecasts about the forthcoming growing season. On the other hand, major investments in irrigation infrastructure cannot be made reactively on such a timescale. Evaluating such investments requires expectations to be formed on costs and benefits over several decades, which places a challenging requirement on

[3] This is sometimes referred to as "planned adaptation" in the literature.

climate and weather forecasting. If the climate changes faster than expected, infrastructure could become obsolete before its planned design-life or require a costly retrofit to increase resilience.

Adaptation will occur in practice in response to particular climate events and in the context of other socio-economic changes.

Responding to changed climate and weather (for example the appearance of stronger and more frequent floods or storms) is often an important first step for adaptation. Enhancing these responses to prepare for future impacts is the second step – for example, by using drought-resistant crops or improving flood defences. Many decisions to adapt will be made autonomously, within existing communities, markets and regulatory frameworks. This has important consequences for the way economists understand and appraise adaptation policy.

First, much adaptation will be triggered by the way climate change is experienced. Climate variability and in particular extreme weather, such as summer heat waves or storms, are likely to constitute important signals, alongside the dissemination of knowledge and information. Since adaptive capacity is related to income and capabilities, the most vulnerable in society will experience the same negative climate impacts more acutely.

Second, many adaptation decisions involve a measure of habit and custom, especially smaller decisions made by, for example, individuals, households and small businesses on short time-scales and with small amounts of resources. This effect may limit the extent to which such adaptations will be orientated towards maximising net benefits in an economic and social sense, since 'custom' may have been based on responding to past climate patterns.

Decisions about the timing and amount of adaptation require that costs and benefits are compared.

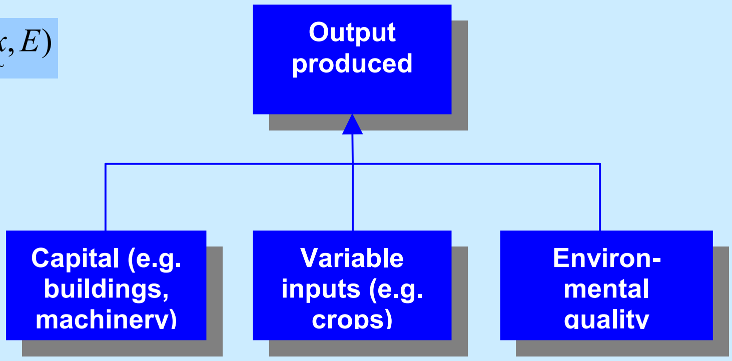
An appraisal of any particular method of adaptation should compare the benefits - which are the avoided damages of climate change - with the costs, appropriately discounted over time (see Chapter 2 and Appendix 2A for a discussion of discounting). The adaptation route that is chosen should be the one that yields the highest net benefit, having taken account of the risks and uncertainties surrounding climate change (see Box 18.2 for a risk management framework).[4]

[4] Callaway and Hellmuth (2006); Willows and Connell (2003).

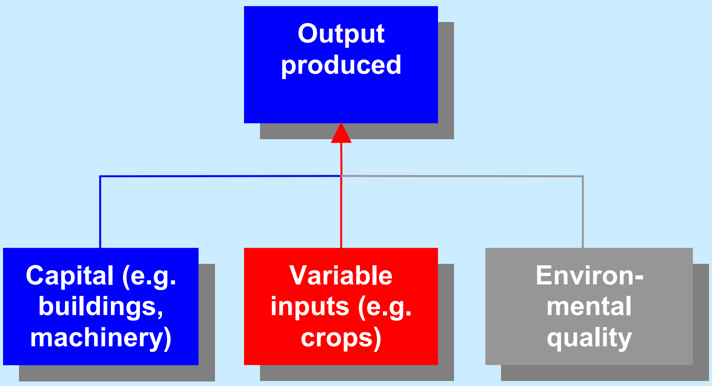
Box 18.1 Adaptation actions with fixed and variable capital stock

The difference between short-run and long-run adaptation decisions can be explained using the following illustrative diagram. In any given year, the output of an economy is generated using three types of inputs, capital *K*, variable inputs to production and environmental quality E.

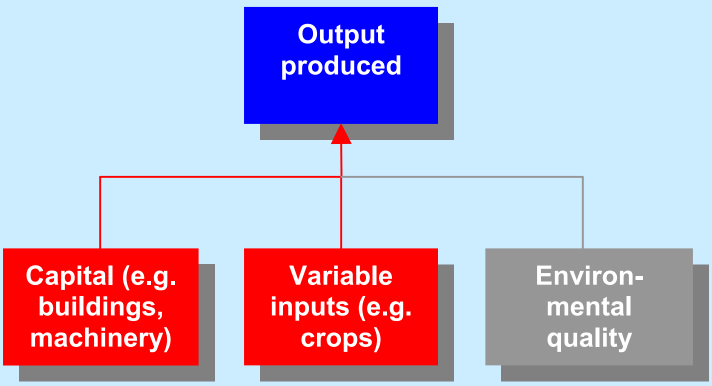
$$Y = f(K, \underset{\sim}{x}, E)$$



In the short run – and given a change in *E* due to climatic change and variability over a short period of time (e.g. one year) – the decision maker, who seeks to maximise the net profits of production, can respond only by changing variable inputs (shown as red in the diagram below).



In contrast, in the long run (e.g. over 30 years), the decision maker can respond by changing both variable inputs and the capital stock to maximise profits given a change.



Box 18.2 Adaptation costs and benefits.

The table below presents a simple framework for thinking about the costs and benefits of adaptation.[5] The columns reflect two climate scenarios, one with and one without climate change (T_0 and T_1 respectively). The two rows represent two adaptation options, one which is best to pursue without climate change and one which is best to pursue with climate change (A_0 and A_1 respectively).

The top left box represents the initial situation, where society is adapted to the current climate (T_0, A_0). The bottom right box represents a situation where society adapts (A_0 to A_1) to a change in climate from T_0 to T_1.

The top right box represents a situation where society fails to adapt to the change in climate. Finally, the bottom left box represents a counterfactual situation where society undertakes adaptation (A_0 to A_1), but the climate does not in the end change. This is an example of the type of situation that could arise if climate does not change in the anticipated way.

Adaptation costs and benefits

Adaptation Type	Existing Climate (T_0)	Altered Climate (T_1)
Adaptation to existing climate (A_0)	Existing climate. Society is adapted to existing climate: (T_0, A_0), or Base Case	Altered climate. Society is adapted to existing climate: (T_1, A_0).
Adaptation to altered climate (A_1)	Existing climate. Society is adapted to altered climate: (T_0, A_1).	Altered climate. Society is adapted to altered climate: (T_1, A_1).

The various costs and benefits of adapting to climate change follow from this, and can be thought of along the following lines:

- *Climate change damage* is the welfare loss associated with moving from the base climate (top left) to a changed climate without adaptation (top right): $W(T_1,A_0) – W(T_0,A_0)$.
- *Net benefits of adaptation* are the reduction in damage achieved by adapting to the changed climate (net of the costs of doing so), subtracting the top right box from the bottom right box: $W(T_1,A_1) – W(T_1,A_0)$.
- *Climate change damage after adaptation* is the difference between social welfare in the bottom right box and in the top left box: $W(T_1,A_1) – W(T_0,A_0)$.

Uncertainty over the nature of future climate change is implicit in this framework, and is one of the principal challenges facing climate policy. The second table below therefore modifies the framework to illustrate the trade-offs facing those planning adaptation under uncertainty.[6] The decision to implement an adaptation strategy should take account of the balance of risks and costs of planning for climate change that does not occur and vice versa.

Where the cost of planning for climate change is low, but the risks posed by climate change are high (top right box), there is a comparatively unambiguous case for adaptation. In contrast, where the costs of adaptation are high but the risks posed by climate change are low (bottom left box), the proposed adaptation responses may be disproportionate to the risks faced. Where the costs of planning for climate change and the risks of climate change are both low (top left box), there is little risk to the situation and the downsides are small, regardless of the choice made. In contrast, where the costs of both 'mistakes' are high, the stakes and risks are very high for the planner.

Cost of planning for climate change	Risks of climate change	
	Low	**High**
Low	Low risk	Plan for climate change
High	Don't plan for climate change	High risk

[5] Drawing on a framework originally presented by Fankhauser (1997) and modified by Callaway (2004).
[6] Callaway and Hellmuth (2006).

More quantitative information on the costs and benefits of economy-wide adaptation is required. For some specific sectors - such as coastal defences and agriculture – some studies indicate that efficient adaptation could reduce climate damages substantially.

As Chapter 6 explained, adaptation is an important component of integrated assessment models that estimate the economy-wide cost of climate change at the regional and global levels. However, these models are currently of limited use in quantifying the costs and benefits of adaptation, because the assumptions made about adaptation are largely implicit. Adaptation costs and benefits are rarely reported separately.[7]

However, for some sectors that are especially vulnerable to climate change, illustrative studies have been undertaken. As with the IAMs discussed in Chapter 6, many assumptions must be made to project costs and benefits over long periods of time. Assumptions about population and economic growth are especially important for evaluating the benefits of adaptation expressed in terms of avoided damage.

For coastal protection, the avoided damages of climate change can be calculated from the value of land, infrastructure, activities and so on protected by sea walls, while the cost of sea walls can be calculated by scaling up from engineering estimates of construction costs. Coastal protection should – in theory – occur up to the point where the cost of the next unit of protection is just equal to the benefit. In general, these studies suggest that high levels of protection may be economically efficient and reduce the costs of land loss substantially.[8] According to one recently analysis, the effectiveness of adaptation declines with higher amounts of sea level rise. This analysis found that for 0.5-m of sea level rise damage costs were reduced by 80 – 90% with enhanced coastal protection than without, while the costs were only reduced by 10 – 70% for 1-m of sea level rise.[9] For most countries, protection costs based on these calculations are likely to be below 0.1% of GDP, at least for rises up to 0.5-m. But for low-lying countries or regions, costs could reach almost 1% of GDP.[10] For 1-m of sea level rise, the costs could exceed several percent of GDP for the most vulnerable nations.[11]

In agriculture, adaptation responses could be even more diverse, ranging from low-cost farm-level actions – such as choice of crop variety, changes in the planting date, and local irrigation – to economy-wide adjustments – including availability of new cultivars, large-scale expansion of irrigation in areas previously only rain-fed, widespread fertiliser application, regional/national shifts in planting date. Some studies suggest that relatively simple and low-cost adaptive measures, such as change in planting date and increased irrigation, could reduce yield losses by at least 30 - 60% compared with no adaptation (Table 18.2).[12] But adaptation gains will be realised only by individuals or economies with the capacity to undertake such adjustments. The costs of implementing adaptation, particularly the transition and learning costs associated with changes in farming regime, have not been clearly evaluated.

[7] Tol *et al*. (1998)
[8] Fankhauser (1995) assumes no population or GDP growth and finds that almost total protection of all coastal cities and harbours in OECD countries would be optimal (e.g. greater than 95% land area protected) and around 80% of open coastline. By allowing for population and GDP growth in line with IPCC scenarios, Nicholls and Tol (2006) find that protecting at least 70% of coastline in most parts of the world could be an optimal protection response.
[9] Anthoff *et al.* (2006) analysing data from Nicholls and Tol (2006) for the decade 2080 - 2089. Costs were calculated as net present value in US $ billion (1995 prices). Damage costs include value of dryland and wetland lost and costs of displaced people (assumed in this study to be three times average per capita income). The ranges represent results for different IPCC socio-economic scenarios with different population and per capita GDP growth trajectories over time.
[10] Analysis in Nicholls and Tol (2006)
[11] This analysis considers only protection costs required to manage loss of land from permanent inundation and not the costs of protection to deal with episodic flooding, which could cause damages an order of magnitude greater (Chapter 5).
[12] Reviewed in Tol *et al.* (1998)

Table 18.2 Benefits of adaptation in agriculture					
Study	**Climate scenario**	**Type of adaptation**	**Climate Impacts**		**Impact change of adaptation**
			without adaptation	**with adaptation**	
Easterling *et al* (1993) Missouri, Iowa, Nebraska, Kansas (MINK)	1930s climate analogue; base year 1980s	Change in planting date tillage practices, change in crops, improved irrigation and crop drought resistance	Yield change ($ bn)		% impact reduction
			-1.33 to –2.71	-0.53 to -1.92	29 - 60
Rosenzweig and Parry (1994) Developed countries Developing countries World	2 x CO_2 base year 2060	Small shifts in planting date (<1 month), change in crops, additional irrigation ('level 1 adaptation')	Change in cereal production %		% impact reduction
			-3.5 to 11.3 -10.8 to –11.00 -1.2 to –7.6	4.0 to 14.0 -9.0 to –12.0 0.0 to –5.0	24 - >100 9 - 17 34 - 100
Adams et al. (1993) United States	2 x CO_2 base year 1990	As Rosenzweig and Parry (1994)	Welfare change ($ bn)		% impact reduction
			2.15 to –13.00	10.82 to – 9.03	>100
Reilly et al. (1994)[a] Developing countries GDP/cap <$500 GDP/cap $500 – 2000 GDP/cap >$2000 E. Europe and former USSR OECD World	2 x CO_2 base year 1989	As Rosenzweig and Parry (1994)	Welfare change ($ bn)		% impact reduction
			-2.07 to –19.83 -1.80 to –15.01 -0.33 to –0.82 1.89 to –10.96 2.67 to – 15.10 -0.13 to –61.23	-0.21 to –10.67 -0.43 to –10.67 -0.60 to –1.02 2.42 to –4.88 5.82 to –6.47 7.00 to –37.62	26 - 90 41 - 76 20 - 46 29 - 56 57 - >100 39 - >100

[a] Based on Rosenzweig and Parry (1994) yield date

Source: Table reproduced from Tol et al. (1998)

18.3 Barriers and limits to adaptation

In many cases, market forces are unlikely to lead to efficient adaptation.

Broadly, there are three reasons for this:

- **Uncertainty and imperfect information**;
- **Missing and misaligned markets,** including public goods;
- **Financial constraints,** particularly those faced by the poor.

Policies can reduce these problems (see Chapters 19 and 20). But policy-makers themselves face imperfect information and have their own organisational challenges. Difficult policy choices may not always be tackled head-on.[13]

Uncertainty and imperfect information

Alongside an increase in global temperatures, climate change will bring increases in regional temperatures, changes in patterns of rainfall, rising sea levels, and increases in extreme events (heatwaves, droughts, floods, storms). High-quality information on future climate change at the regional scale is important for a market-based mechanism that drives successful adaptation responses. In particular, information is required for markets to operate efficiently. Without a robust and

[13] Lonsdale *et al.* (2005) explored these challenges in the Atlantis Project, where key London decision-makers faced a collapse of the West Antarctic Ice Sheet beginning in 2030, and a 30% chance of a 5-metre rise in sea level by 2130. They found that a delay to approve construction of an outer barrier in the Thames by decision-makers meant that abandonment of parts of London became the only adaptation option.

reliable understanding about the likely consequences of climate change, it is difficult for individuals – or firms – to weigh up the costs and benefits of investing in adaptation. Uncertainty in climate change projections could therefore act as a significant impediment to adaptation. The uncertainty will never be completely resolved, but should become more constrained as our understanding of the system improves.

As this understanding improves and develops, there may also be a role for markets in providing information to individuals. For example, better developed insurance markets would help to create clear price signals – for example through differentiated insurance premia - about the risks associated with climate change. Thus premia associated with buildings in high flood risk areas might be expected to be higher than those on buildings in less vulnerable locations.

Missing and misaligned markets, including public goods

Autonomous adaptation is more likely when the benefits will accrue solely – or predominantly – to those investing in adaptation. For sectors that are characterised by short planning horizons – and where there is less uncertainty about the potential impacts of climate change - successful adaptive responses may therefore be driven by autonomous decisions.

However, effective adaptation of long-term investment patterns (such as climate-proofing buildings and defensive infrastructure) could prove challenging for private markets, especially with uncertain information. Decisions that leave a long-lasting legacy require private agents to weigh the uncertain future benefits of adaptation against its more certain current costs (see also Box 18.2). Even if the benefits of adaptation can be realised over a relatively short time-horizon, unless those paying the costs can fully reap the benefits, then there will be a barrier to adaptation. For example, there will be little financial incentive for developers to increase resilience of new buildings unless property buyers discriminate between properties on the basis of vulnerability to future climate.

Evidence from the United States suggests that consumers often fail to adopt even low-cost protection against weather hazards. A report by the Wharton Center for Risk Management and Decision Processes cites major surveys of residents in hurricane- and earthquake-prone areas of the USA. It found that, in the majority of cases, no special efforts had been made to protect homes.[14] Willingness-to-pay research suggests that many property owners are reluctant to invest in cost-effective protection measures, because they do not make the implied trade-off between spending money on risk prevention measures now in return for potential benefits over time. Some may not be in a position to finance the investment. Some may expect the government to bail them out.[15] Others may believe that the benefits of investment will not be capitalised in the value of the home.

Some adaptive responses not only provide private benefits to those who have paid for them, they also provide benefits – or positive spillovers - to the wider economy. In such circumstances, the private sector is unlikely to invest in adaptation up to the socially desirable level because they are unable to capture the full benefits of the investment. In some cases, there may be little – or no – private adaptation because the necessary adaptative response is effectively a ‘public good’ in the technical economic sense[16]. Public goods occur where those who fail to pay for something cannot be excluded from enjoying its benefits, and where one person’s consumption of a good does not diminish the amount available for others. In the case of climate change, relevant pubic goods include research to improve our understanding of climate change and its likely impacts, coastal protection and emergency disaster planning. These – and the appropriate policy response – are discussed more fully in chapters 19 and 20.

Financial constraints and distributional impacts

Upfront investment in adaptive capacity and adaptation actions will be financially constrained for those on low incomes. In many developing countries, financial resources in general are already extremely limited, and poverty already limits the ability to cope with and recover from climate shocks - particularly when combined with other stresses (Chapter 20 discusses the particular challenge faced by developing countries).

[14] Kleindorfer and Kunreuther (2000)
[15] Kydland and Prescott (1977)
[16] Samuelson (1954).

Equally, across all countries, it will be the poorest in society that have the least capacity to adapt (Chapters 4 and 5 in Part II). Thus, the impacts of climate change could exacerbate existing inequalities by limiting the ability of poor people to afford insurance cover or to pay for defensive actions. Social safety nets that function in emergencies could be of great importance here: for example cash or food for work schemes, such as those involved in employment guarantee schemes in India, can play a very important role in droughts.

Even with an appropriate policy framework, adaptation will be constrained both by uncertainty and technical limits to adaptation.

An inherent difficulty for long-term adaptation decisions is uncertainty, due to limitations in our scientific knowledge of a highly complex climate system and the likely impacts of perturbing it. Even as scientific understanding improves, there will always remain some residual uncertainty, as the size of impacts also depend on global efforts to control greenhouse gas emissions. Effective adaptation will involve decisions that are robust to a range of plausible climate futures and are flexible so they can be modified relatively easily. But there will always be a cost to hedging bets in this way, compared to the expert 'optimal' adaptation strategy that is revealed only with the benefit of hindsight.

There are clear limits to adaptation in natural ecosystems. Even small changes in climate may be disruptive for some ecosystems (e.g. coral reefs, mangrove swamps) and will be exacerbated by existing stresses, such as pollution. Beyond certain thresholds, natural systems may be unable to adapt at all, such as mountainous habitats where the species have nowhere to migrate.

But even for human society, there are technical limits to the ability to adapt to abrupt and large-scale climate change, such as a rapid onset of monsoon failure in parts of South Asia. Sudden or severe impacts triggered by warming could test the adaptive limits of human systems. Very high temperatures alone could become lethal, while lack of water will undermine people's ability to survive in a particular area, such as regions that depend on glacier meltwater. Rising sea levels will severely challenge the survival of low-lying countries and regions such as the Maldives or the Pacific Islands, and could result in the abandonment of some highly populated coastal regions, including several European cities.[17]

18.4 Conclusions

There are many ways that people, governments and economic agents of all kinds can adapt to climate change. Indeed, adaptation has always occurred in response to changes in the climate system. However, adaptation by private individuals will have to be bolstered by government support in a variety of ways, if countries and regions are to rise to the challenge of climate change this century and beyond.

Uncertainty and imperfect information, missing and misaligned markets, and financial and distributional constraints, especially on the poorest in society, will present barriers to adaptation to climate change. Chapters 19 and 20 discuss the role of both markets and government in helping to promote effective adaptation in developed and developing countries.

In all cases, however, it is important to recognise the limits to adaptation. Although it can mute the impacts of climate change, it cannot by itself solve the problems posed by high and rapidly increasing temperatures. Even for relatively low amounts of warming, there are natural and technical constraints to adaptation – as is made vividly clear in low-lying coastal regions. Equally, without strong and early mitigation, the physical limits to – and costs of – adaptation will grow rapidly.

[17] Tol *et al.* (2006) investigated possible responses of society to 5 – 6 m of sea level rise following collapse of the West Antarctic Ice Sheet. The scenarios were developed from case studies based on interviews with stakeholders and experts. In the Rhone delta, the most likely option would be retreat. In the Thames Estuary, there could be a mix of protection and retreat with parts of the city turned into a Venice-style canal city. In the Netherlands, the initial response would be protection, followed by retreat from areas of low economic value, with eventual abandonment of some large cities, like Amsterdam and Rotterdam.

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Developing an economic framework for examining adaptation was one of the primary objectives of a workshop hosted by the Stern Review in London on 9 May 2006. Several valuable papers were presented at the workshop, all of which are on the Review website (http://www.sternreview.org.uk). Sam Fankhauser summarised his previous work on developing an economic framework for adaptation (see Fankhauser 1997), while Molly Hellmuth presented her work with Mac Callaway (building on Callaway 2004). Frans Berkhout provided a valuable complement to these papers, discussing how we should understand adaptation by private individuals and the role of the public sector in that light (drawing on Berkhout, 2005). On the measurement of adaptation costs and benefits, Tol *et al.* (1998) reviewed evidence from a range of sources. Their discussion of estimates generated by global integrated assessment models is valuable.

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