13 Towards a Goal for Climate-Change Policy

Key Messages

Reducing the expected adverse impacts of climate change is both highly desirable and feasible. The need for strong action can be demonstrated in three ways: by comparing disaggregated estimates of the damages from climate change with the costs of specific mitigation strategies, by using models that take some account of interactions in the climate system and the global economy, and by comparing the marginal costs of abatement with the social cost of carbon.

The science and economics both suggest that a shared international understanding of the desired goals of climate-change policy would be a valuable foundation for action. Among these goals, aiming for a particular target range for the ultimate concentration of greenhouse gases (GHGs) in the atmosphere would provide an understandable and useful guide to policy-makers. It would also help policy-makers and interested parties at all levels to monitor the effectiveness of action and, crucially, anchor a global price for carbon. Any long-term goal would need to be kept under review and adjusted as scientific and economic understanding developed.

However, the first key decision, to be taken as soon as possible, is that strong action is indeed necessary and urgent. This does not require immediate agreement on a precise stabilisation goal. But it does require agreement on the importance of starting to take steps in the right direction while the shared understanding is being developed.

Measuring and comparing the expected benefits and costs over time of different potential policy goals can provide guidance to help decide how much to do and how quickly. Given the nature of current uncertainties explored in this Review, and the ethical issues involved, analysis can only suggest a range for action.

The current evidence suggests aiming for stabilisation somewhere within the range 450 - 550ppm CO_2e. Anything higher would substantially increase risks of very harmful impacts but would only reduce the expected costs of mitigation by comparatively little. Anything lower would impose very high adjustment costs in the near term for relatively small gains and might not even be feasible, not least because of past delays in taking strong action.

For similar reasons, weak action over the next 20 to 30 years, by which time GHG concentrations could already be around 500ppm CO_2e, would make it very costly or even impossible to stabilise at 550ppm CO_2e. **There is a high price to delay.** Delay in taking action on climate change would lead both to more climate change and, ultimately, higher mitigation costs.

Uncertainty is an argument for a more, not less, demanding goal, because of the size of the adverse climate-change impacts in the worse-case scenarios.

Policy should be more ambitious, the more societies dislike bearing risks, the more they are concerned about climate-change impacts hitting poorer people harder, the more optimistic they are about technology opportunities, and the less they discount future generations' welfare purely because they live later. The choice of objective will also depend on judgements about political feasibility. These are decisions with such globally significant implications that they will rightly be the subject of a broad public debate at a national and international level.

The ultimate concentration of greenhouse gases anchors the trajectory for the social cost of carbon. **The social cost of carbon is likely to increase steadily over time, in line with the expected rising costs of climate-change-induced damage. Policy should therefore ensure that abatement efforts at the margin also intensify over time. But policy-makers should also spur on the development of technology that can drive down the average costs of abatement.** The social cost of carbon will be lower at any given time with sensible climate-change policies and efficient low-carbon technologies than under 'business as usual'.

Even if all emissions stopped tomorrow, the accumulated momentum behind climate change would ensure that global mean temperatures would still continue to rise over the next 30 to 50 years. Thus **adaptation is the only means to reduce the now-unavoidable costs of climate change over the next few decades. But adaptation also entails costs, and cannot cancel out all the effects of climate change**. Adaptation must go hand in hand with mitigation because, otherwise, the pace and scale of climate change will pose insurmountable barriers to the effectiveness of adaptation.

13.1 Introduction

It is important to use both science and economics to inform policies aimed at slowing and eventually bringing a stop to human-induced climate change.

Science reveals the nature of the dangers and provides the foundations for the technologies that can enable the world to avoid them. Economics offers a framework that can help policy-makers decide how much action to take, and with what policy instruments. It can also help people understand the issues and form views about both appropriate behaviour and policies. The scientific and economic framework provides a structure for the discussions necessary to get to grips with the global challenge and guidance in setting rational and consistent national and international policies.

Reducing the expected adverse impacts of climate change is both desirable and feasible.

Previous chapters argued that, without mitigation efforts, future economic activity would generate rising greenhouse gas emissions that would impose unacceptably high economic and social costs across the entire world. Fortunately, technology and innovation can help rein back emissions over time to bring human-induced climate change to a halt. This chapter first makes the case for strong action now, and then discusses how a shared understanding around the world of the nature of the challenge can guide that action on two fronts: mitigation and adaptation.

13.2 The need for strong and urgent action

The case for strong action can be examined in three ways: a 'bottom-up' approach, comparing estimates of the damages from unrestrained climate change with the costs of specific mitigation strategies; a 'model-based' approach taking account of interactions in the climate system and the global economy; and a 'price-based' approach, comparing the marginal costs of abatement with the social cost of carbon.

The 'bottom-up' approach was adopted in Chapters 3, 4 and 5 of this Review for the heterogeneous impacts of climate change, and in Chapters 8 and 9 for the scale and costs of possible mitigation strategies. If global temperatures continue to rise, there will be mounting risks of serious harm to economies, societies and ecosystems, mediated through many and varied changes to local climates. The impacts will be inequitable. It is not necessary to add these up formally into a single monetary aggregate to come to a judgement that human-induced climate change could ultimately be extremely costly. Chapter 7 showed that, without action, greenhouse-gas emissions will continue to grow, so these risks must be taken seriously. But Chapter 9 showed that it is possible to identify technological options for stabilising greenhouse gas concentrations in the atmosphere that would cost of around 1% of world gross world product – moderate in comparison with the high cost of potential impacts. The options considered there are not the only ways of tackling the problem, nor necessarily the best. But they do demonstrate that the problem can be tackled. And there will be valuable co-benefits, such as reductions in local air pollution.

The 'model-based' approach was illustrated in Chapter 6 for the impacts, and Chapter 10 for the costs, of mitigation. Models make it easier to consider the quantitative implications of different degrees of action and can build in some behavioural responses, both to climate change and the policy instruments used to combat it. But they do so at the cost of considerable simplification. They also require explicit decisions about the ethical framework appropriate for aggregating costs and benefits of action. The model results surveyed in this Review point in the same direction as the 'bottom up' evidence: the benefits of strong action clearly outweigh the costs.

In broad brush terms, spending somewhere in the region of 1% of gross world product on average forever could prevent the world losing the equivalent of 5 - 20% of gross world product for ever, using the approach to discounting explained in Chapters 2 and 6.

This can be thought of as akin to an investment. Putting together estimates of benefits and costs of mitigation through time, as in Figures 13.1 and 13.2, shows how incurring relatively modest net costs this century (peaking around 2050) can earn a big return later on, because of the size of the damages averted. These charts are quantitative analogues to the schematic diagram in Figure 2.4 comparing a 'business as usual' trajectory with a mitigation path. They are drawn assuming mitigation costs to be a constant 1% (Figure 13.1) and 4% (Figure 13.2) of gross world product and taking a 'business as usual' scenario with baseline climate scenario, some risk of catastrophes and a rough-and-ready estimate of non-market impacts. As explained in Chapter 6, this is now likely to underestimate the sensitivity of the climate to greenhouse gas emissions. Also, the charts focus on impacts measured in terms of how they might affect output, not wellbeing; in other words, they do not reflect the more appropriate approach to dealing with risk, as advocated in Chapter 2. But the range between the 5th and 95th percentiles of the distribution of possible impacts under the specific scenario is shown.

Figure 13.1 'Output gap' between the '550ppm $C0_2$e and 1% GWP mitigation cost' scenario and BAU scenario, mean and 5th – 95th percentile range

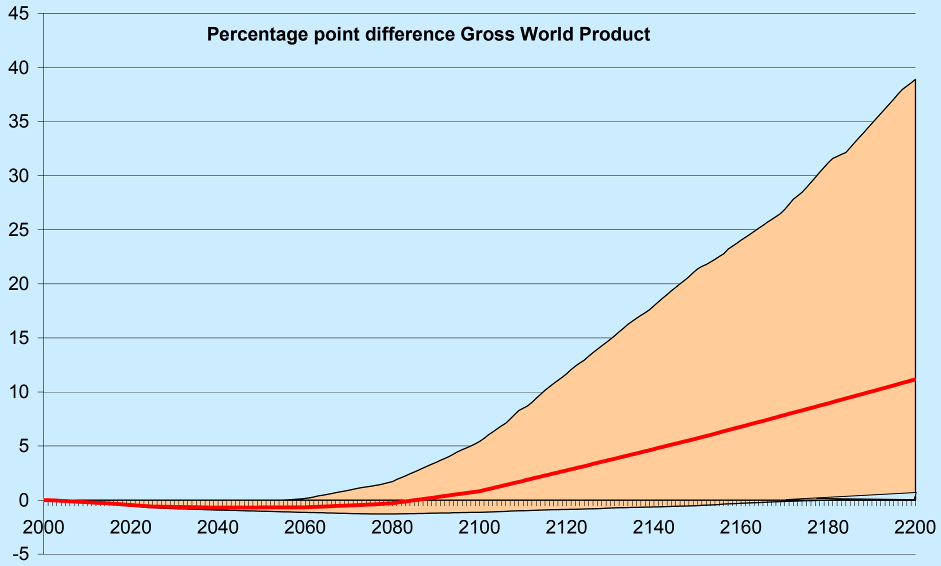
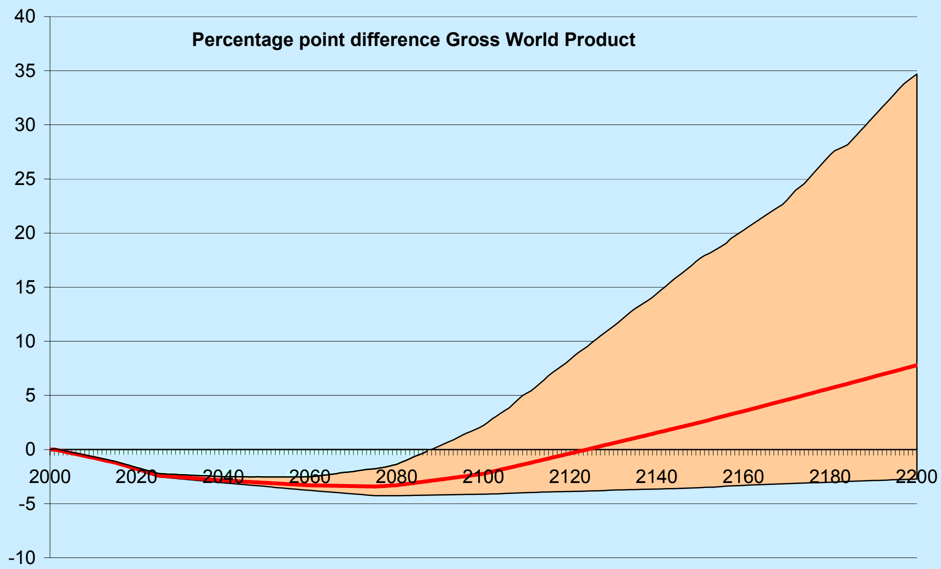


Figure 13.2 'Output gap' between the '550ppm $C0_2$e and 4% GWP mitigation cost' scenario and BAU scenario, mean and 5th – 95th percentile range



The 'price-based' approach compares the marginal cost of abatement of emissions with the 'social cost' of greenhouse gases. Consider, for example, the social cost of carbon – that is, the impact of emitting an extra unit of carbon at any particular time on the present value (at that time) of expected wellbeing or utility[1]. The extra emission adds to the stock of carbon in the atmosphere for the lifetime of the relevant gas, and hence increases radiative forcing for a long time. The size of the impact depends not only on the lifetime of the gas, but also on the size of the stock of greenhouse gases while it is in the atmosphere, and how uncertain climate-change impacts in the future are valued and discounted. The social cost of carbon has to be expressed in terms of a numeraire, such as current consumption, and is a relative price. If this price is higher than the cost, at that time, of stopping the emission of the extra unit of carbon – the marginal abatement cost – then it is worth undertaking the extra abatement, as it will generate a net benefit. In other words, if the marginal cost of abatement is lower than the marginal cost of the long-lasting damage caused by climate change, it is profitable to invest in abatement.

The 'price-based' approach points out that estimates of the social cost of carbon along 'business as usual' trajectories are much higher than the marginal abatement cost today. The academic literature provides a wide range of estimates of the social cost of carbon, spanning three orders of magnitude, from less than £0/tC (in year 2000 prices) to over £1000/tC (see Box 13.1), or equivalently from less than $0/tCO_2$ to over $400/tCO_2$. This is obviously an extremely broad range and as such makes a policy driven by pricing based on an estimate of the social cost of carbon difficult to apply. The mean value of the estimates in the studies surveyed by Tol was around $29/tCO_2$ (2000 US$), although he draws attention to many studies with a much lower figure than this.

The modelling approach that was illustrated in Chapter 6 of this Review also indicates the sensitivities of estimates of the social cost of carbon to assumptions about discounting, equity weighting and other aspects of its calculation, as described by Tol, Downing and others. Preliminary analysis of the model used in Chapter 6 points to a number around $85/tCO_2$ (year 2000 prices) for the central 'business as usual' case, using the PAGE2002 valuation of non-market impacts. It should be remembered that this model is different from its predecessors, in that it incorporates both explicit modelling of the role of risk, using standard approaches to the economics of risk, and makes some allowance for catastrophe risk and non-market costs, albeit in an oversimplified way. In our view, these are very important aspects of the social cost of carbon, which should indeed be included in its calculation even though they are very difficult to assess. We would therefore point to numbers for the 'business as usual' social cost of carbon well above (perhaps a factor of three times) the Tol mean of $29/tCO_2$ and the 'lower central' estimate of around $13/tCO_2$ in the recent study for DEFRA (Watkiss et al. (2005)). But they are well below the upper end of the range in the literature (by a factor of four or five). Nevertheless, we are keenly aware of the sensitivity of estimates to the assumptions that are made. Closer examination of this issue – and a narrowing of the range of estimates, if possible – is a high priority for research.

The case for strong action from the perspective of comparing the 'business as usual' social cost of carbon and the marginal abatement cost is powerful, even if one takes Tol's mean or the Watkiss lower benchmark as the value of the former, when one compares it with the opportunities for low-cost reductions in emissions and, indeed, for those that make money (see Chapter 9). It is still more powerful if one takes higher numbers for the social cost of carbon, as we would suggest is appropriate, and also recognises that the SCC will increase over time, because of the current and prospective increases in the stock of greenhouse gases in the atmosphere.

All three of these approaches would lead to exactly the same estimate of the net benefits of climate-change policies and the same extent of action if models were perfect and policy-makers had full information about the world. In practice, these conditions do not hold, so the three perspectives can be used to cross-check the broad conclusions from adopting any one of them.

[1] The social cost of carbon and carbon price discussed here are convenient shorthand for the social cost (and corresponding price) for each individual greenhouse gas. Their relative social costs, or 'exchange rate', depend on their relative global warming potential (GWP) over a given period and when that warming potential is effective, as the latter determines the economic valuation of the damage done. Suppose there were a gas with a life in the atmosphere one tenth that of CO_2 but with ten times the GWP while it is there. The social cost of that gas today would be less than the social cost of CO_2, because it would have its effect on the world while the total stock of greenhouse gases was lower on average, so that its marginal impact would be less in economic terms.

Box 13.1 Estimates of the social cost of carbon

Downing et al (2005), in a study for DEFRA, drew the following conclusions from the review of the range of estimates of the social cost of carbon:

- The estimates span at least three orders of magnitude, from 0 to over £1000/tC (2000 £), reflecting uncertainties in climate and impacts, coverage of sectors and extremes, and choices of decision variables
- A lower benchmark of £35/tC is reasonable for a global decision context committed to reducing the threat of dangerous climate change. It includes a modest level of aversion to extreme risks, relatively low discount rates and equity weighting
- An upper benchmark for global policy contexts is more difficult to deduce from the present state of the art, but the risk of higher values for the social cost of carbon is significant.

The Downing study draws on Tol (2005), who gathered 103 estimates from 28 published studies. Tol notes that the range of estimates is strongly right-skewed: the mode was $2/tC (1995 US$), the median was $14/tC, the mean $93/tC and the 95th percentile $350/tC. He also finds that studies that used a lower discount rate, and those that used equity weighting across regions with different average incomes per head generated higher estimates and larger uncertainties. The studies did not use a standard reference scenario, but in general considered 'business as usual' trajectories. (See also Watkiss et al (2005) on the use of the social cost of carbon in policy-making and Clarkson and Deyes (2002) for earlier work on the social cost of carbon in a UK context.)

NB conversion rates:
£100/tC (2000 prices) = $116/tC (1995 prices) = $35.70/t$CO_2$ (2000 prices)

13.3 Setting objectives for action

Having made the case for strong action, there remains the challenge of formulating more specific objectives, so that human-induced climate change is slowed and brought to a halt without unnecessary costs. The science and economics both suggest that a shared international understanding of what the objectives of climate-change policy should be would be a valuable foundation for policy.

The problem is global. Policy-makers in different countries cannot choose their own global climate. If they differ about what they think the world needs to achieve, not only will many of them be disappointed, the distribution of efforts to reduce emissions will be inefficient and inequitable. The benefits of a shared understanding include creating consensus on the scale of the problem and a common appreciation of the size of the challenge for both mitigation and adaptation. It would provide a foundation for discussion of mutual responsibilities in tackling the challenge. At a national and individual level, it would reduce uncertainty about future policy, facilitating long-term planning and making it more likely that both adaptation and mitigation would be appropriate and cost-effective.

The ultimate objective of stopping human-induced climate change can be translated into a variety of possible long-term global goals to give guidance about the strength of measures necessary.

Table 13.1 below summarises five types of goal, each defining key stages along the causal chain from emissions to atmospheric concentrations, to global temperature changes and finally to impacts.

Table 13.1 Five types of goal		
	Advantages	**Disadvantages**
Maximum tolerable level of impacts (e.g. no more than a doubling of the current population under water stress)	-Linked directly to the consequences to avoid.	-Scientific, economic and ethical difficulties in defining which impacts are important and what level of change can be tolerated. -Uncertainties in linking avoidance of a specific impact to human action. -Success not measurable until too late to take further action.
Global mean warming (above a baseline)	-Can be linked to impacts (with a degree of uncertainty). -One quantifiable variable.	-Uncertainties in linking goal with specific human actions. -Lags in time between temperature changes and human influence, so difficult to measure success of human actions in moving towards the goal.
Concentration(s) of greenhouse gases (or radiative forcing)	-One quantifiable variable. -Can be linked to human actions (with a degree of uncertainty). -Success in moving towards the goal is measurable quickly.	-Uncertainties about the magnitude of the avoided impacts.
Cumulative emissions of greenhouse gases (over a given time period)	-One quantifiable variable. -Directly linked to human actions. -Success in moving towards the goal is measurable quickly.	-Uncertainties about the magnitude of the avoided impacts.
Reduction in annual emissions by a specific date	-One quantifiable variable. -Success in moving towards the goal is measurable quickly.	-Uncertainties about the magnitude of the avoided impacts. -Does not address the problem that impacts are a function of stocks not flows. -May limit 'what, where, when' flexibility and so push up costs

These different types of goal are not necessarily inconsistent, and some are more suited to particular roles than others. Public concern focuses on impacts to be avoided, and this is indeed the language of the UNFCCC, which defines the ultimate objective of the Convention as "*…to achieve…stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*" However, this does not provide a quantitative guide to policy-makers on the action required. The EU has defined a temperature threshold – limiting the global average temperature change to less than 2°C above pre-industrial. This goal allows policy-makers and the public to debate the level of tolerable impacts in relation to one simple index, but it does not provide a transparent link to the level of mitigation action that must be undertaken.

The analysis presented in Chapter 8, linking cumulative emissions first to long-run concentrations in the atmosphere, and then to the probabilities of different ultimate temperature outcomes, provides an alternative basis for long-term goals. It is one that allows the level of and uncertainty about both impacts and the costs of mitigation to be debated together. Once a shared understanding of what the broad objectives of policy should be has been established, it is useful to go further and translate it into terms that can guide the levels at which the instruments of policy should be set.

Any operational goal should be closely related to the ultimate impacts on wellbeing that policy seeks to avoid. But, if it is to guide policy-makers in adjusting policy sensibly over time, progress towards it must also be easy to monitor. The goal therefore should be clear, simple and specific; it must be possible to use new information regularly to assess whether recent observations of the variable targeted are consistent with hitting the goal. Policy-makers must also have some means of adjusting policy settings to alter the trajectory of the variable targeted. Seeing policy-makers adjust policy settings in this way to keep their aim on the goal would also build the credibility of climate-change policies. This is very important, if private individuals and firms are to play their full part in bringing about the necessary changes in behaviour.

A goal for atmospheric concentrations would allow policy-makers to monitor progress in a timely fashion and, if the world were going off course, adjust policy instrument settings to correct the direction of travel.

The rest of this chapter focuses on the question of what concentration of greenhouse gases in the atmosphere, measured in CO_2 equivalent, to aim for. Policy instruments should be set to make the expected long-run outcome for concentration (on the basis of today's knowledge) equal to this level. Atmospheric concentration is closer than cumulative emissions in the causal chain to the impacts with which climate-change policy is ultimately concerned. And, compared with other possible formulations of policy aspirations such as global temperature change, observations of atmospheric concentration allow more rapid feedback to policy settings[2].

Such a goal is a device to help structure and calibrate climate-change policy. But it is only a means to an end – limiting climate change – and it is useful to keep that ultimate objective in mind. Other intermediate and local goals (for example, national limits for individual countries' annual emissions or effective carbon-tax rates) may also help to move economies towards the long-run objective and to monitor the success of policy, given the long time it will take to achieve stabilisation – as long as they are consistent with, and subsidiary to, the primary goal. They may also be necessary as stepping-stones towards the adoption of a more comprehensive and coherent global objective, given the time it is likely to take to reach a shared understanding of what needs to be done. The danger is that multiple objectives may reduce the efficiency with which the main one is pursued. Part VI of the Review considers some of the problems of turning an international objective into obligations for national governments. This chapter sidesteps those problems in order to focus on what economics suggests might be desirable characteristics of the set of local, national and supranational policies that emerge from the political process.

However, the key decision required now is that strong action is both urgent and necessary. That does not require immediate agreement on a precise stabilisation goal.

It is important to start taking steps in the right direction while the shared understanding is being developed.

13.4 The economics of choosing a goal for global action

Measuring and comparing the expected benefits and costs over time associated with different stabilisation levels can provide guidance to help decide how much to do and how quickly.

Estimates need to take account of the great uncertainties about climate-change damages and mitigation costs that remain even when a specific stabilisation goal is being considered. The time dimension is also important. A different stabilisation goal entails a different trajectory of emissions through time, so analysis should not simply compare the costs and benefits of extra emission reductions this year. Instead, one needs to compare incremental changes in the present values of current and future costs and benefits.

The marginal benefits of a lower stabilisation level reflect the expected impact on people's wellbeing of achieving a lower expected ultimate temperature change and a reduced risk of extreme outcomes. Risk will increase along the path towards stabilisation and cannot be accounted for simply by comparing ultimate stabilisation levels. As Chapter 2 showed, this requires judgements about how wellbeing is affected by risk, uncertainty and the distribution of the impacts of climate change across individuals and societies. Subjective assessments have to be made where objective evidence about risks is limited, particularly those associated

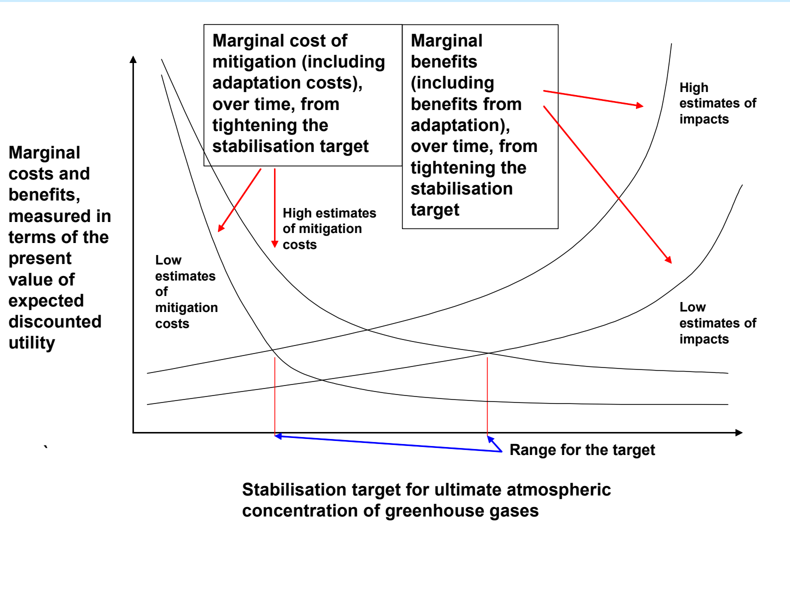
[2] Cumulative emissions are closer to the policy-induced emissions reductions that incur the *costs* of mitigating climate change. The choice between the two goals comes down to how the costs and benefits of missing the goal by some amount differ in the two cases, given uncertainty about the relationship between the two variables due to uncertainty about the functioning of carbon 'sinks', etc. This is related to the issue of whether setting greenhouse-gas prices or quotas is preferable in the face of uncertainty (see Chapter 14); the arguments there imply that, for the long run, a concentration goal is to be preferred).

with more extreme climate change. These assessments should adopt a consistent approach towards risk and uncertainty, reflecting the degree of risk aversion people decide is appropriate in this setting.

The marginal costs of aiming for a lower stabilisation level reflect the need to speed up the introduction of mitigation measures, such as development of low-carbon technologies and switching demand away from carbon-intensive goods and services. Stabilisation, however, requires emissions to be cut to below 5 $GtCO_2e$ eventually, to the Earth's natural annual absorption limit, whatever the specific GHG stock level chosen (Chapter 8).

Figure 13.3 illustrates the approach sketched here. The figure shows in schematic fashion how the incremental or marginal benefits and costs of a programme of action change through time (in terms of present values) as successively lower goals are considered. As explained in Chapter 2, the benefits (and the costs) of action should be thought of in terms of the expected impacts on wellbeing over time, appropriately discounted, not simply monetary amounts. That allows for risk weighting, risk aversion and considerations of fairness across individuals and generations to be incorporated in the analysis. For simplicity, two 'marginal benefits' curves are drawn to remind the reader of the huge uncertainties. In practice, people differ about the weights they attach to different sorts of climate-change impacts. There is scope for legitimate debate about how they should be aggregated to compare them with the costs of mitigation.

Figure 13.3 Schematic representation of how to select a stabilisation level



The costs of mitigation, too, should be thought of in terms of their impact on broad measures of wellbeing. It matters on whom the costs fall, when they are incurred and what the uncertainties about them are. Figure 13.2 shows two curves, for high and low estimates of the incremental costs of tougher action to curb emissions. They are drawn with the costs rising more sharply as the stabilisation level considered becomes lower and lower. The ideal objective is where the marginal benefits of tougher action equal the marginal costs. Given the uncertainty about both sides of the ledger, this approach cannot pin down a precise number but can, as the chart indicates, suggest a range in which it should lie. The range excludes levels where either the incremental costs of mitigation or the incremental climate-change impacts are rising very rapidly.

Uncertainty is an argument for setting a more demanding long-term policy, not less, because of the asymmetry between unexpectedly fortunate outcomes and unexpectedly bad ones.

Suppose there is a probability distribution for the scale of physical impacts associated with a given increase in atmospheric concentrations of greenhouse gases. As one moves up the probability distribution, the consequences for global wellbeing become worse. But, more than that, the consequences are likely to get worse at an accelerating rate, for two reasons. First, the higher the temperature, the more rapidly adverse impacts are likely to increase. Second, the worse the outcome, the lower will be the incomes of people affected by them, so any monetary impact will have a bigger impact on wellbeing[3].

There is a second line of reasoning linking uncertainty with stronger action. There is an asymmetry due to the very great difficulty of reducing the atmospheric concentration of greenhouse gases. Increases are irreversible in the short to medium run (and very difficult even in the ultra-long run, on our current understanding). If new information is collected that implies that climate-change impacts are likely to be *worse* than we now think, we cannot go back to the concentration level that would have been desirable had we had the new information earlier. But if the improvement in knowledge implies that a *less* demanding goal is appropriate, it is easy to allow the concentration level to rise faster. In other words, there is an option value to choosing a lower goal than would be picked if no improvements in our understanding of the science and economics were anticipated. The 'option value' argument is not, however, clear-cut[4]. There is also an option value associated with delaying investment in long-lived structures, plant and equipment for greenhouse gas abatement. Investments in physical capital, like cumulative emissions, are largely irreversible, so there is an option value to deferring them. That argues for a higher level of annual emissions than otherwise desirable.

Some of the parameters that modellers have treated as uncertain, such as discount factors and equity weights, reflect societies' preferences. In the process of agreeing an international stabilisation objective, or at least narrowing its range, discussions have to resolve, or at least reduce disagreement over, the issues of social choice lying behind these uncertainties.

As explained in Chapter 2 and its appendix, this Review argues for using a low rate of pure time preference and assuming a declining marginal utility of consumption as consumption increases across time, people and states of nature. However, the magnitude of the risks described in Part II of this Review suggests that a broad range of perspectives on these two issues indicates the need for strong action to mitigate emissions.

Given this framework, the evidence on the costs and benefits of mitigation reviewed in the chapters above can give a good indication of upper and lower limits that might be set for the extent of action, as argued below. The policy debate should seek some indication of where within these limits international collective action should aim[5]. But it is vital that, while a shared understanding permitting agreement on a common goal is being developed, initial actions to reduce emissions are not delayed.

There is room for debate about precisely how fast emissions need to be brought down, but not about the direction in which the world now has to move.

13.5 Climate change impacts and the stabilisation level

Expected climate-change impacts rise with the atmospheric concentration of greenhouse gases, because the probability distributions for the long-run global temperature move upwards. The evidence strongly suggests that 550ppm CO_2e would be a dangerous place to be, with substantial risks of very unpleasant outcomes.

Figure 13.3 illustrates how the risk of various impacts occurring is associated with different stabilisation levels[6] (see also Box 8.1 for frequency distributions of the range of temperature increases associated with various stabilisation levels in a selection of climate models). The top section shows the 5 – 95% probability ranges of temperature increases projected at different stabilisation levels; the central marker is the 50th percentile point. The bottom section

[3] More formally, we take impacts to be convex in atmospheric concentration and note that the expected utility of a range of outcomes is lower than the utility of the expected outcome, if marginal utility declines with income. This is discussed further in Chapter 2.
[4] See, for example, Kolstad (1996), Pindyck (2000) and Ingham and Ulph (2005)
[5] If policy-makers adopt a zone rather than a single number as a goal, recognising that no policy is able to ensure that a point goal can be hit precisely, it should be within these upper and lower limits. It would also be desirable if the zone were considerably narrower than the span of those limits, so as not to weaken substantially the discipline on policy-makers to adjust policy settings if it looks as if the goal is not going to be met. Too wide a target zone also increases the risk of different policy-makers around the world choosing policy settings that are inconsistent with each other.
[6] Where the risk is defined using subjective probabilities based on current knowledge of climate sensitivity – the relationship between greenhouse gas concentration and temperatures.

shows the projected impacts. At some point, the risks of experiencing some extremely damaging phenomena begin to become significant. Such phenomena include:

- Irreversible losses of ecosystems and extinction of a significant fraction of species.
- Deaths of hundreds of millions of people (due to food and water shortages, disease or extreme weather events).
- Social upheaval, large-scale conflict and population movements, possibly triggered by severe declines in food production and water supplies (globally or over large vulnerable areas), massive coastal inundation (due to collapse of ice sheets) and extreme weather events.
- Major, irreversible changes to the Earth system, such as collapse of the Atlantic thermohaline circulation and acceleration of climate change due to carbon-cycle feedbacks (such as weakening carbon absorption and higher methane releases) – at high temperatures, stabilisation may prove more difficult, or impossible, because such feedbacks may take the world past irreversible tipping points (chapter 8).

The expected impacts of climate change on well-being in the broadest sense are likely to accelerate as the stock of greenhouse gases increases, as argued in Chapter 3. The expected benefits of extra mitigation will therefore increase with the stabilisation level[7]. In Figure 13.2, the marginal benefit curve is therefore drawn as rising increasingly steeply with the stabilisation level. There are four main reasons:

- As global mean temperatures increase, several specific climate impacts are likely to increase more and more rapidly: in other words, the relationship is convex. Examples include the relationship between windstorm wind-speed and the value of damage to buildings (IAG (2005)) and new estimates of the relationship between temperature and crop yields (Schlenker and Roberts (2006));
- Different elements of the climate system may interact in such a way that the combined impacts rise more and more rapidly with temperature;
- As global mean temperatures increase several degrees above pre-industrial levels, existing stresses would be more and more likely to trigger the most severe impacts of climate change that arise from interactions with societies, namely social upheaval, large-scale conflict and population movements;
- As global mean temperatures increase, so does the risk that positive feedbacks in the climate system, such as permafrost melting and weakening carbon sinks, kick in.

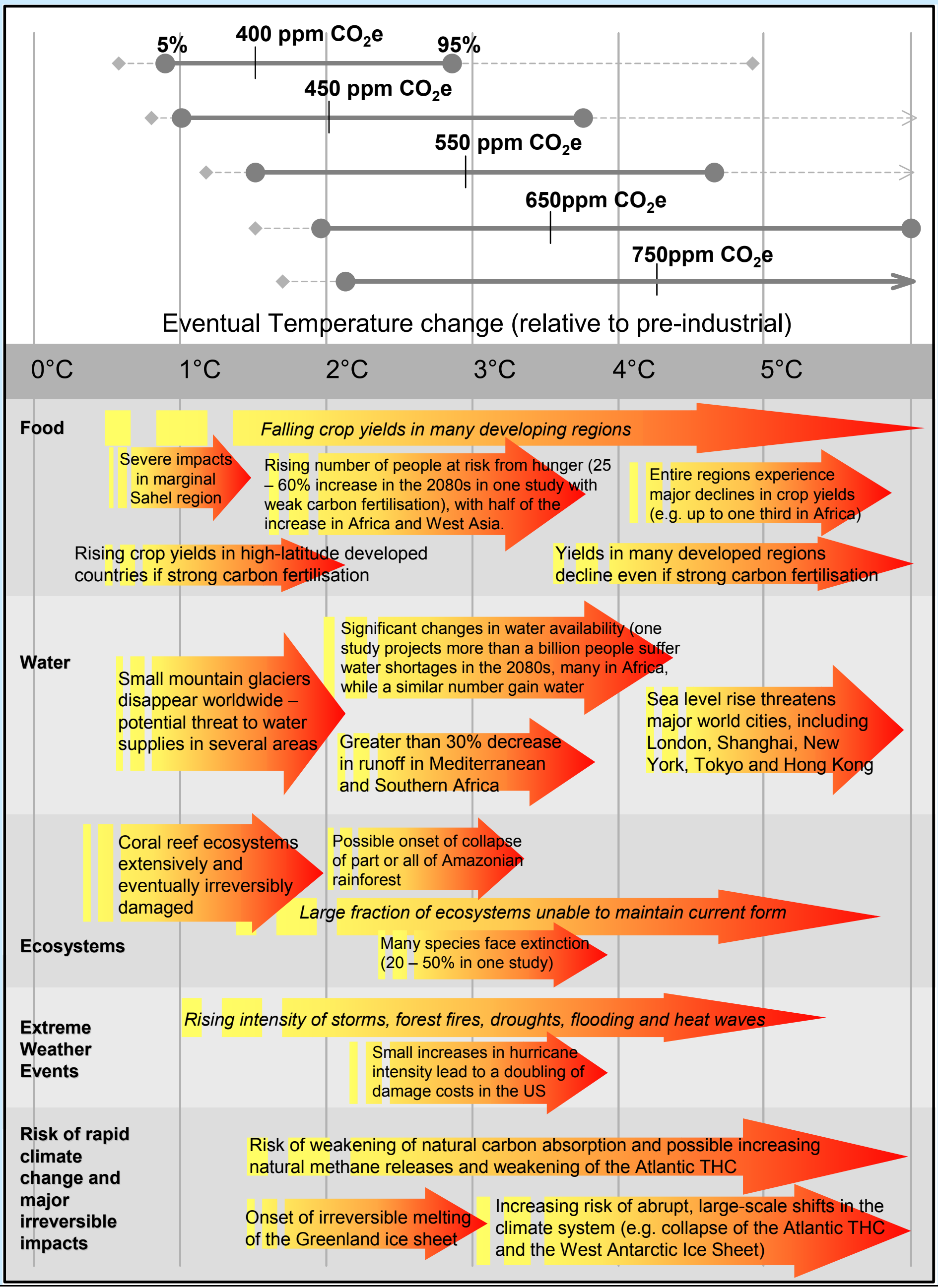
The uncertainties about impacts make it impossible to quantify exactly where the marginal impacts of climate change will rise more sharply. However, across the current body of evidence, two approximate global turning points appear to exist, at around 2 – 3°C and 4 – 5°C above pre-industrial levels:

- At roughly 2 – 3°C above pre-industrial, a significant fraction of species would exceed their adaptive capacity and, therefore, rates of extinction would rise. This level is associated with a sharp decline in crop yields in developing counties (and possibly developed counties) and some of the first major changes in natural systems, such as some tropical forests becoming unsustainable, irreversible melting of the Greenland ice sheet and significant changes to the global carbon cycle (accelerating the accumulation of greenhouse gases).
- At around 4 – 5°C above pre-industrial, the risk of major abrupt changes in the climate system would increase markedly. At this level, global food production would be likely to fall significantly (even under optimistic assumptions), as crop yields fell in developed countries.

[7] There is, however, considerable uncertainty about how climate-change effects will evolve as temperatures rise, as many of the hypothesised effects are expected to take place or intensify outside the temperature range experienced by humankind, and so cannot be verified by empirical observation. One characteristic of the climate physics works in the opposite direction: the expected rise in temperature is a function of the *proportional* increase in the stock of greenhouse gases, not its *absolute* increase. As a result, some integrated assessment models, for example Nordhaus' DICE model, have S-shaped functions to represent the costs of climate-change impacts.

Figure 13.4 Stabilisation levels and probability ranges for temperature increases

The figure below illustrates the types of impacts that could be experienced as the world comes into equilibrium with higher greenhouse gas levels. The top panel shows the range of temperatures projected at stabilisation levels between 400ppm and 750ppm CO_2e at equilibrium. The solid horizontal lines indicate the 5 – 95% range based on climate sensitivity estimates from the IPCC TAR 2001 (Wigley and Raper (2001)) and a recent Hadley Centre ensemble study (Murphy et al. (2004)). The vertical line indicates the mean of the 50th percentile point. The dashed lines show the 5 – 95% range based on eleven recent studies (Meinshausen (2006)). The bottom panel illustrates the range of impacts expected at different levels of warming. The relationship between global average temperature changes and regional climate changes is very uncertain, especially with regard to changes in precipitation (see Box 3.2). This figure shows potential changes based on current scientific literature.



Few studies have examined explicitly the benefits of choosing a lower stabilisation level. Generally, those that have done so show that the benefits vary across sectors. For example, in reducing the stabilisation temperature from 3.5°C to 2.5°C, significant benefits to ecosystems and in the number of people exposed to water stress have been estimated[8].

[8] Arnell et al. (2004)

However, such evidence is strongly model-dependent and, therefore, subject to significant uncertainties.

Recent integrated assessment models (discussed in Chapter 6) have attempted to capture some of these uncertainties by representing damage functions stochastically. These cover several dimensions, including the risk of major abrupt changes in the climate systems (they do not, however, generally include estimates of the potential costs of social disruption). They also take account of adaptation to climate change to varying extents. Chapter 6 notes that such models show a steep increase in marginal costs with rising temperature. The PAGE2002 model, used in chapter 6, has the advantage of allowing for the uncertainty in the literature about several dimensions of impacts. It permits a comparison of the probability distribution of projected gross world product net of the cost of climate change with the hypothetical gross world product without climate change, for a given increase in global mean temperature, thus providing an estimate of climate-change costs (see Table 13.2, where estimates include some measure of 'non-market' impacts). The costs of climate change as a proportion of gross world product are modelled as an uncertain function of the increase in temperature, among other factors.

Table 13.2 Estimates of the costs of climate change by temperature increase, as a proportion of gross world product, from PAGE2002

	Mean expected cost	5th percentile	95th percentile
2°C	0.6%	0.2%	4.0%
3°C	1.4%	0.3%	9.1%
4°C	2.6%	0.4%	15.5%
5°C	4.5%	0.6%	23.3%

Source: Hope (2003)

Thus, for example, according to PAGE2002, if the temperature increase rises from 2ºC to 3ºC, the mean damage estimate increases from 0.6% to 1.4% of gross world product; but the 'worst case' – the 95th percentile of the probability distribution – goes from 4.0% to 9.1%. These costs fall disproportionately on low-latitude, low-income regions, but there are significant net costs in higher-latitude regions, too.

The estimates of the costs of impacts suggest that the mean expected damages rise significantly if the global temperature change rises from 3ºC to 4ºC and even more from 4ºC to 5ºC. But the damages associated with a 'worst case' scenario – the 95th percentile of the distribution – rise more rapidly still.

On the basis of current scientific understanding, it is no longer possible to prevent all risk of dangerous climate change.

Box 8.1 showed how the risk of exceeding these temperature thresholds rises at stabilisation levels of 450, 550, 650, and 750ppm CO_2e. This box implies:

- Even if the world were able to stabilise at current concentrations, it is already possible that the ultimate global average temperature increase will exceed 2°C
- At 450ppm CO_2e, there is already a 18% chance of exceeding 3°C, according to the Hadley ensemble reported in the table, but a very high chance of staying below 4°C
- By 550ppm CO_2e, there is a 24% chance that temperatures will exceed 4°C, but less than a 10% chance that temperatures will exceed 5°C.

It can be seen that a move above 550ppm CO_2e would entail considerable additional costs of climate change, taking into account the further increases in the risks of extreme outcomes.

Our work with the PAGE model suggests that, allowing for uncertainty, if the world stabilises at 550ppm CO_2e, climate change impacts could have an effect equivalent to reducing consumption today and forever by about 1.1%[9]. As Chapter 6 showed, this compares with around 11% in the corresponding 'business as usual' case – ten times as high. With stabilisation at 450ppm CO_2e, the percentage loss would be reduced to 0.6%, so choosing the tougher goal 'buys' about 0.5% of consumption now and forever. Choosing 550ppm instead of 650ppm CO_2e 'buys' about 0.6%. As with all models, these numbers reflect heroic

[9] These figures are based on the 'broad impacts, standard climate sensitivity' case among the scenarios considered in Chapter 6. As such, they do not allow for equity weighting; if they did, the estimates in the text would be higher. They would also be higher if higher estimates of climate sensitivity, incorporating more amplifying feedback mechanisms, were used. The valuation of non-market impacts is particularly difficult and dependent on ethical judgements, as explained in Chapter 6.

assumptions about the valuation of potential impacts, although, as Chapter 6 explains, they reflect an attempt to ensure the model calibration reflects the nature of the problem faced. They also entail explicit judgements about some of the ethical issues involved. In addition, the PAGE2002 model is not ideal for analysing stabilisation trajectories. Nevertheless, all integrated assessment models are sensitive to the assumptions and they should be taken as only indicative of the quantitative impacts, given those assumptions. It should be noted that the results quoted from Chapter 6 leave out much that is important, and the other models referred to there leave out more.

13.6 The costs of mitigation and the stabilisation level

The lower the stabilisation level chosen, the faster the technological changes necessary to bring about a low-carbon society will have to be implemented.

Stabilising close to the current level of greenhouse gas concentration would require implausibly rapid reductions in emissions, because the technologies currently available to achieve such reductions are still very expensive[10] and the appropriate structures, plant and equipment are not yet in place. Hitting 450ppm CO_2e, for example, appears very difficult to achieve with the current and foreseeable technologies, as suggested in Chapter 8. It would require an early peak in emissions, very rapid emission cuts (more than 5% per year), and reductions by 2030 of around 70%. Even with such cuts, the stock of greenhouse gases covered by the Kyoto Protocol would initially overshoot, their effect temporarily masked by aerosols (so that there would be only a very small overshoot in radiative forcing)[11]. Costs would start to rise very rapidly if emissions had to be reduced sharply before the existing capital stock in emissions-producing industries would otherwise be replaced and at a speed that made structural adjustments in economies very abrupt and hence expensive. Abrupt changes to economies can themselves trigger wider impacts, such as social instability, that are not covered in economic models of the costs of mitigation.

Technological change eventually has to get annual emissions down to their long-run sustainable levels without having to accelerate sharply the retirement of the existing capital stock, if costs are to be contained. Model-based estimates of the present value of the costs of setting a tougher stabilisation objective are not widely available in the literature. That reflects, among other factors, the unavoidable uncertainties about the pace and costs of future innovation. In principle, such estimates ought to reflect the incidence of the mitigation costs, which ultimately fall on the consumers of currently GHG-intensive goods and services, as well as their monetary value (just as the incidence of climate-change impacts matters as well as their level), but there has been little investigation of this aspect of the problem.

However, there are some estimates to help as a guide. Chapter 9 in effect argued that the extra mitigation costs incurred by stabilising at around 550ppm CO_2e instead of allowing business to continue as usual would probably be of the order of 1% of gross world product. Choosing a lower goal would cost more, a higher goal less. Some studies of costs give more of an indication of their sensitivity to the stabilisation objective. For example, the study by Edenhofer et al (2006), averaging over five models, provides the following estimates of cost increases from choosing a lower stabilisation goal:

Table 13.3 Some model-based estimates of the increase in mitigation costs from reducing a stabilisation goal (discounted percentage of gross world output), by discount rate used

	5% pa	'Green Book'	2% pa	1% pa	0% pa
Moving from 500ppm to 450ppm CO_2	0.25%	0.39%	0.43%	0.51%	0.58%
Moving from 550ppm to 500ppm CO_2	0.06%	0.11%	0.12%	0.14%	0.18%

Source: adapted from Edenhofer et al. (2006); 'Green Book' is a declining discount rate over time, as in HM Treasury Green Book project-appraisal guidance.

[10] Costs of delivering any particular level of abatement are likely to decline with investment and experience; see Chapters 9 and 16.

[11] The world is already at around 430ppm CO_2e if only the greenhouse gases covered by the Kyoto Protocol are included; but aerosols reduce current radiative forcing. The projection reported in the text assumes that the aerosol affect diminishes over time, but for a period counteracts a temporary rise in Kyoto greenhouse gases above 450ppm CO_2e. As the concentration of greenhouse gases is rising at around 2.5 ppm CO_2e per year, and annual emissions are increasing, 450ppm CO_2e could be reached in less than ten years.

It is important to note that these results are tentative, and that there is still much debate about the role of induced technological progress, the focus of the study. Nevertheless, the bottom line in Table 13.3 suggests that the extra mitigation costs from choosing a goal of around 500ppm instead of 550ppm CO_2 would be small, ranging from 0.06% to 0.18% of gross world output, depending on how much future costs are discounted. In terms of a CO_2e goal, this is similar to going from 600 – 700ppm to 550 – 650ppm, depending on what happens to non-CO_2 greenhouse gases (see Chapter 8). The extra costs of choosing a goal of 450ppm CO_2 instead of 500ppm CO_2 would be higher, ranging from 0.25% to 0.58%; this is similar to going from 550 – 650ppm CO_2e to 500 – 550ppm CO_2e. None of the discount schemes used are the same as the one used in Chapter 6 of this Review, as the discount rates are not path-dependent. However, as stabilisation reduces the chances of very bad outcomes compared with 'business as usual', the discounting issue is less important than when evaluating potential impacts without mitigation. It is important to note that the studies concerned take the year 2000 as a baseline. Given the probable cumulative emissions since then, the goals would now be more difficult and expensive to hit.

The recent US Climate Change Science Program draft report on scenarios of greenhouse gas emissions and atmospheric concentrations also provides useful estimates, reporting for various points in time the percentage change in gross world product expected due to adopting policies to meet four different stabilisation goals[12]. Again, the studies covered take 2000 as the base year. The implications for incremental costs (as a fraction of gross world output) of adopting successively tougher goals are summarised in Table 13.4 below. These studies were not designed with the objective of this chapter in mind, of course, and the draft is subject to revision, so the estimates should be regarded as suggestive of magnitudes, not definitive.

Table 13.4 Some model-based estimates of the incremental savings in mitigation costs from relaxing a stabilisation goal (% of gross world output in the relevant year)

Incremental change	Model	2020	2040	2060	2080	2100
Moving from around 550ppm to around 450ppm CO_2 (670ppm to 525ppm CO_2e)	IGSM	1.6%	2.9%	4.4%	6.2%	9.3%
	MERGE	0.7%	1.3%	1.5%	1.2%	0.7%
	MiniCAM	0.2%	0.6%	1.0%	0.8%	0.6%
Moving from around 650ppm to around 550ppm CO_2 (820ppm to 670ppm CO_2e)	IGSM	0.3%	0.8%	1.4%	2.1%	3.7%
	MERGE	0.0%	0.1%	0.3%	0.4%	0.5%
	MiniCAM	0.0%	0.1%	0.3%	0.4%	0.3%
Moving from around 750ppm to 650ppm CO_2 (970ppm to 820ppm CO_2e)	IGSM	0.1%	0.2%	0.5%	0.9%	1.4%
	MERGE	0.0%	0.0%	0.1%	0.1%	0.1%
	MiniCAM	0.0%	0.0%	0.0%	0.1%	0.3%

Source: Adapted from US CCSP Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Draft for public comment, June 26, 2006[13]

Table 13.4 shows in the bottom panel that the extra costs incurred by adopting an objective of around 820ppm instead of 970ppm CO_2e are very small, and, for two of the three models (MERGE and MiniCAM in the middle panel), aiming for around 670ppm instead of 820ppm CO_2e also costs little. According to the same two models, choosing 525ppm instead of 670ppm CO_2e increases costs by around 1% of gross world product, the amount varying somewhat over time. The most pessimistic model here generates considerably higher

[12] US CCSP Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Draft for public comment, June 26, 2006.

[13] The ranges in terms of CO_2e are derived from the long-run constraints on total radiative forcing in the modelling exercise.

estimates for the total yearly costs of mitigation, reflecting its relatively high trajectory for 'business as usual' emissions and relatively pessimistic assumptions about the likely pace of innovation in low-carbon technologies. The studies suggest that mitigation costs start to rise sharply towards the bottom of the ranges of stabilisation levels considered.

Delay will make it more difficult and more expensive to stabilise at or below 550ppm CO_2e.

All of these studies take as a starting point the year 2000. If it takes 20 years or so before strong policies are put in place globally, it is likely that the world would already be at somewhere around 500ppm CO_2e, making it very difficult and expensive then to take action to stabilise at around 550ppm.

13.7 A range for the stabilisation objective

Integrated assessment models have been used in a number of studies to compare the marginal costs and marginal benefits of climate-change policy over time. But many of the estimates in the literature do not take into account the latest science or treat risk and uncertainty appropriately. Doing so would bring down the stabilisation level desired.

In some cases, the models have been used to estimate the 'optimal' amount of mitigation that maximises benefits less costs. These studies recommend that greenhouse gas emissions be reduced below business-as-usual forecasts, but the reductions suggested have been modest. For example, on the basis of the climate sensitivities and assessments available at the time the studies were undertaken,

- Nordhaus and Boyer (1999) found that the optimal global mitigation effort reduces atmospheric concentrations of carbon dioxide from 557ppm in 2100 (business-as-usual) to 538ppm. This reduces the global mean temperature from an estimated 2.42°C above 1900 levels to 2.33°C;
- Tol (1997) found that the optimal mitigation effort reduces the global mean temperature in 2100 from around 4°C above 1990 levels to between around 3.6°C and 3.9°C, depending on whether countries cooperate and on the costs of mitigation;
- Manne et al. (1995) did not use their model to find the optimal reduction in emissions, but the policy option they explored that delivers the highest net benefits reduces atmospheric concentrations of carbon dioxide from around 800ppm in 2100 to around 750ppm, reducing global mean temperature from around 3.25°C above 1990 levels to around 3°C.

However, the optimal amount of mitigation may in fact be greater than these studies have suggested. Above all, they carry out cost-benefit analysis appropriate for the appraisal of small projects, but we have argued in Chapter 2 that this method is not suitable for the appraisal of global climate change policy, because of the very large uncertainties faced. As a result, these studies underestimate the risks associated with large amounts of warming. Neither does any of these studies place much weight on benefits and costs accruing to future generations, as a consequence of their ethical choices about how to discount future consumption. Manne et al. apply a much higher discount rate to utility than do we in Chapter 6. Nordhaus and Boyer assume relatively low and slowing economic growth in the future, which reduces future warming. Tol estimates relatively modest costs of climate change, even at global mean temperatures 5-6°C above pre-industrial levels. Recent scientific developments have placed more emphasis on the dangers of amplifying feedbacks of global temperature increases and the risks of crossing irreversible tipping points than these models have embodied.

Given the paucity of estimates of the appropriate stabilisation level and the disadvantages of the ones that exist, this chapter does not propose a specific numerical goal. Instead, it explores how economic analysis can at least help suggest upper and lower limits to the range for an atmospheric concentration goal. Allowing for the current uncertainties, the evidence suggests that the upper limit to the stabilisation range should not be above 550ppm CO_2e.

Putting together our results on the valuation of climate-change impacts with the mitigation-cost studies suggests that the benefits of choosing a lower stabilisation goal clearly outweigh the costs until one reaches 550 – 600ppm CO_2e. But around this level the cost-benefit calculus starts to get less clear-cut. The incremental mitigation costs of choosing 500 – 550ppm instead of 550 – 600ppm CO_2e are three to four times as much as the incremental costs of choosing 550 – 600ppm instead of 600 – 650ppm CO_2e, according to the numbers in Edenhofer et al. The higher mitigation costs incurred if 500 – 550ppm is chosen instead of 550 – 600ppm CO_2e might be of similar size to the incremental benefits. They would be bigger if induced technological change were inadequate or 'business as usual' emissions were at the higher end of projections, as in the IGSM projections reported in Table 13.4.

As far as the climate-change impacts are concerned, the incremental benefits might be bigger than these calculations allow – for example, if policy-makers are more risk-averse than the PAGE calculations assumed or attach more weight to non-market impacts. Nevertheless, in choosing an upper limit to the stabilisation range, one needs to consider what is appropriate if climate-change impacts turn out to be towards the low end of their probability distribution (for a given atmospheric concentration) and mitigation costs towards the high end of their distribution. Following broadly this approach, but assuming mitigation costs are brought down over time by induced technological change, we suggest an upper limit of 550ppm CO_2e.

The lower limit to the stabilisation range is determined by the level at which further tightening of the goal becomes prohibitively expensive. On the basis of current evidence, stabilisation at 450ppm CO_2e or below is likely to be very difficult and costly.

Cost estimates derived from modelling exercises suggest that costs as a share of gross world product would increase sharply if a very ambitious goal were adopted (see Chapter 10). It is instructive that cost modelling exercises rarely consider stabilisation below 500ppm CO_2e. Edenhofer et al point out that some of the models in their study simply cannot find a way of achieving 450ppm CO_2e. Even stabilising at 550ppm CO_2e would require complete transformation of the power sector. 450ppm CO_2e would in addition require very large and early reductions of emissions from transport, for which technologies are further away from deployment. Given that atmospheric greenhouse gas levels are now at 430ppm CO_2e, increasing at around 2.5ppm/yr, the feasibility of hitting 450ppm CO_2e without overshooting is very much in doubt. And it would be unwise to assume that any overshoot could be clawed back.

The evidence on the benefits and costs of mitigation at different atmospheric concentrations in our view suggests that the stabilisation goal should lie within the range 450 – 550ppm CO_2e.

The longer action is delayed, the higher will be the lowest stabilisation level achievable. The suggested range reflects in particular the judgements that:

- Any assessment of the costs of climate change must take into account uncertainty about impacts and allow for risk aversion. Because of the risk of very adverse impacts, extreme events and amplifying feedbacks, this implies adopting a tougher goal than if uncertainty were ignored
- Proper weight should be given to the interests of future generations. Future individuals should be given the same weight in ethical calculations as those currently alive, if it is certain that they will exist. But, as there is uncertainty about the existence of future generations, it is appropriate to apply some rate of discounting over time. That points to the use of a positive, but small, rate of pure time preference (see Chapter 2 and its appendix)
- Proper attention should be paid to the distribution of climate-change impacts, in particular to the disproportionate impact on poor people
- Productivity growth in low-greenhouse-gas activities will speed up if there is more output from and investment in these activities
- The speed of decarbonisation is constrained by the current state of technology and the availability of resources for investment in low-carbon structures, plant, equipment and processes.

It is clear that studies of climate-change impacts and of mitigation costs do not yet establish a narrow range for the level at which the atmospheric concentrations of greenhouse gases should be stabilised. More research is needed to narrow the range further. There will always be disagreements about the size of the risks being run, the appropriate policy stance towards risk, and the valuation of social, economic and ecological impacts into the far future. But the range suggested here provides room for negotiation and debate about these. And we would argue that agreement on the range stated does not require signing up to all of the judgements specified above. In presenting the arguments, for example, we have omitted a number of important factors that are likely to point to still higher costs of climate change and thus still higher benefits of lower emissions and a lower stabilisation goal.

In any case, agreement requires discussion and negotiation about the ethical issues involved. Chapter 6 demonstrates that taking proper account of the non-marginal nature of the risks from climate change leads to a higher estimate of risk-adjusted losses of wellbeing than if the larger risks are ignored or submerged in simple averages. Those who weigh more heavily the potential costs of the climate change possible at any given stabilisation level will argue for a goal towards the lower end of the range. Greater risk aversion and more concern for equity across regions and generations will push in the same direction. But those who are pessimistic about the direction and pace of technological developments or who believe emissions under 'business as usual' will grow more rapidly than generally expected will tend to advocate a goal towards the upper limit, other things being equal.

The EU has adopted an objective, endorsed by a large number of NGOs and policy think-tanks, to limit global average temperature change to less than 2°C relative to pre-industrial levels. This goal is based on a precautionary approach. A peak temperature increase of less than 2°C would strongly reduce the risks of climate-change impacts, and might be sufficient to avoid certain thresholds for major irreversible change – including the melting of ice-sheets, the loss of major rainforests, and the point at which the natural vegetation becomes a source of emissions rather than a sink. Some would argue that the implications of exceeding the 2°C limit are sufficiently severe to justify action at any cost. Others have criticised the 2°C limit as arbitrary, and have raised questions about the feasibility of the action that is required to maintain a high degree of confidence of staying below this level. Recent research on the uncertainties surrounding temperature projections suggests that at 450ppm CO_2e there would already be a more-than-evens chance of exceeding 2°C (see Chapter 8). This highlights the need for urgent action and the importance of keeping quantitative objectives under review, so that they can be updated to reflect the latest scientific and economic analysis.

Some of the uncertainties will be resolved by continuing progress in the science of climate change, but ethics and social values will always have a crucial part to play in decision-making. The precise choice of policy objective will depend on values, attitudes to risk and judgements about the political feasibility of the objective. It is a decision with significant implications that will rightly be the subject of a broad public and international debate.

13.8 Implications for emissions reductions and atmospheric concentrations

Stabilisation of atmospheric concentrations implies that annual greenhouse-gas emissions must peak and then fall, eventually reaching the level that the Earth system can absorb annually, which is likely to be below 5 GtCO_2e.

At the moment, annual emissions are over 40 GtCO_2e. Chapter 8 showed how, for the range of stabilisation levels considered here, annual emissions should start falling within the next 20 years, if implausibly high reduction rates are to be avoided later on. Global emissions will have to be between 25% and 75% lower than current levels by 2050. That illustrates the fact that, even at the high end of the stabilisation range, major changes in energy systems and land use are required within the next 50 years.

While annual emissions are likely to rise first and then fall, atmospheric concentrations are likely to continue to rise until the long-term objective is reached.

For any given stabilisation level, overshooting entails increased risks of climate change, by increasing the chances of triggering extreme events associated with higher concentration levels than the goal, and amplifying feedbacks on concentration levels. The expected impacts on wellbeing associated with any stabilisation level are thus likely to be smaller if overshooting is avoided. As reducing emissions in agriculture appears relatively difficult, and that sector accounts for more than 5 GtCO_2e per year by itself already, stabilisation is likely ultimately (well beyond 2050) to require complete decarbonisation of all other activities and some net sequestration of carbon from the atmosphere (e.g. by growing and burning biofuels, and capturing and storing the resultant carbon emissions, or by afforestation). Overshooting and return require that annual emissions can at some stage be reduced for a period below the level consistent with a stable level of the stock of greenhouse gases. On the basis of the current economic and technological outlook, that is likely to be very difficult.

Setting up a long-run stabilisation goal does not, however, preclude future revisions to make it more ambitious, if either technological progress is more far-reaching than anticipated or the expected impacts of rises in concentration levels rise. But, equally, unexpected difficulties in driving technical progress or a downward revision in expected impacts of climate change would warrant a less challenging goal. Given the pervasive uncertainties about both costs and benefits of climate-change policies, it is essential that any policy regime incorporate from the outset mechanisms to update the long-run goal in a transparent fashion in response to new developments in the science or economics.

The precise trajectory of annual emissions will depend on, among other factors, how climate-change policy is implemented, the pace of economic growth and the extent of innovation, particularly in the energy sector. Chapter 9 demonstrated that mitigation is more likely to be carried out cost effectively if policy encourages 'what, where and when' flexibility, so setting a precise trajectory as a firm intermediate objective is likely to be unnecessarily costly. Trajectories can nevertheless give a guide as to whether emissions are on course to reach the long-term goal.

13.9 The social cost of carbon

Calculations of the social cost of carbon have commonly been used to show the price that the world has to pay, if no action is taken on climate change, for each tonne of gas emitted – as in Section 13.2. But the concept can also be used to evaluate the damages along a stabilisation trajectory[14].

Choosing a concentration level to aim for also anchors a trajectory for the social cost of carbon. Without having a specific stabilisation goal in mind, it is difficult to calibrate what the carbon price should be – or, more generally, how strong action should be. The social cost of carbon will be lower at any given time with sensible climate-change policies than under 'business as usual'.

The social cost of carbon will be lower, the lower the ultimate stabilisation level. The social cost of carbon depends on the overall strategy for mitigating climate change and can help support that strategy, for instance by helping to evaluate abatement proposals. But it should not be seen as the driver of strategy. If the ultimate stabilisation goal has been chosen sensibly, the social cost of carbon along the stabilisation trajectory should be a good guide to the carbon price needed to help persuade firms to make the carbon-saving investments and undertake the research and development that would help deliver the necessary changes and entice consumers to buy fewer GHG-intensive goods and services. However, as Part IV of this Review argues, carbon pricing is only part of what needs to be done to bring down emissions.

If the concentration of carbon in the atmosphere rises steadily towards its long-run stabilisation level (so there is no overshooting), and expected climate-change damages accelerate with concentrations, the social cost of carbon will rise steadily over time, too[15]. An extra unit of carbon will do more damage at the margin the later it is emitted, because it will be around in the atmosphere while concentrations are higher, and higher concentrations mean larger climate-change impacts at the margin[16].

The social cost of carbon will be lower at any given time with sensible climate-change policies than under 'business as usual', because concentrations will be lower at all points in time. Hence, *for given assumptions about discounting and the other relevant factors*, the social cost of carbon associated with sensible emissions strategies is likely to be considerably lower than

[14] The social cost of carbon is well defined along any specific emissions trajectory, not only stabilisation trajectories, as the usual calculations of 'business as usual' SCCs illustrate.

[15] This requires that the convexity of the relationship between expected damages (in terms of broad measures of wellbeing) and global mean temperature increases outweighs the declining marginal impact of increases in concentration on temperature as concentration rises.

[16] The social cost of carbon can also be thought of as the shadow price of carbon if there are no other distortions in the economy, apart from the greenhouse-gas externality, affected by emissions. The shadow-price path over time will depend on the precise dynamics of expected growth, climate-change impacts, the rate of removal of CO_2 from the atmosphere, discount rates and the marginal utility of income. The social cost of carbon is likely to rise faster, the higher is expected economic growth, the higher the rate at which total impacts rise with concentrations, the higher the decay rate of the greenhouse gases, and the higher the pure rate of time preference.

estimates reviewed in the recent DEFRA study, which were based on various 'business as usual' scenarios[17].

The social cost of carbon will also be lower if the efficiency of emissions-abatement methods improves rapidly and new low-carbon technologies prove to be cheap and easy to spread around the world. In that case, it would be worthwhile undertaking more mitigation and a lower stabilisation level would be appropriate. The lower stabilisation level and path drive down the SCC – better technology is a means to that end. Policy nevertheless has to be strong enough to bring about the changes in technology and energy demand necessary to stabilise at the chosen level.

Compared with the assumptions lying behind the estimates of the social cost of carbon reported in the DEFRA study, there are a number of aspects of this Review's framework of analysis that tend to push up the implied social cost of carbon. These include:

- The adoption of a full 'expected utility' approach to valuation of impacts, allowing risk aversion to give more weight to the possibility of bad outcomes
- Greater weight given to 'non-market' outcomes, especially life chances in poor countries[18]
- The use of a low pure rate of time preference, reflecting the view that this rate should be based largely on the probability that future generations exist, rather than their having some more lowly ethical status[19]
- Equity weighting
- The weight given to recent work on uncertainty about climate sensitivity
- The weight given to recent work on amplifying-feedback risks within the climate system to global temperatures and the risks of extreme events

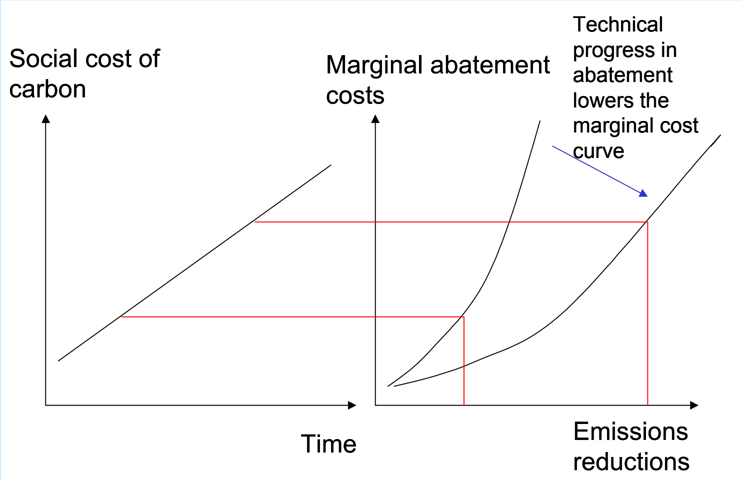
Policy should ensure that abatement efforts intensify over time. Emissions reductions should be driven to the point where their marginal costs keep pace with the rising social cost of carbon.

Firms and individuals are likely to undertake abatement activities up to the point where the marginal costs of reducing carbon emissions are equal to the carbon price, given by the social cost of carbon associated with the desired trajectory. Anticipated improvements in the overall efficiency of emissions reductions should be reflected in quantity adjustments – lower emissions – not a fall in the price of carbon. The rising SCC is driven by the rising atmospheric concentration of greenhouse gases and the marginal abatement costs are brought into equality with the SCC by firms' and households' reactions to the carbon price. This is illustrated in Box 13.2.

Marginal abatement costs are a measure of effort. If in any region or sector they fall below the estimated social cost of carbon, not enough is being done – unless emissions have ceased. Over time, it may become much easier to reduce emissions in some sectors. Some models suggest an eventual fall in marginal abatement costs in the energy sector, for example, as a result of technological progress. If that does happen, the sector can become completely decarbonised. But elsewhere, where complete decarbonisation will not have taken place – for example, transport – efforts should increase over time and the marginal abatement cost should continue to rise. But policy-makers should foster the development of technology that can drive down the *average* costs of abatement over time.

[17] Watkiss et al. (2005)
[18] While we have counselled against excessively formal monetary approaches to the value of life, losses of life from climate change nevertheless should weigh heavily in any assessment of damages from climate change.
[19] Note that this is not the same as a low discount rate. The higher the growth rate, the higher the discount rate (see Chapter 2 and its appendix).

Box 13.2 The relationship between the social cost of carbon and emissions reductions



Up to the long-run stabilisation goal, the social cost of carbon will rise over time because marginal damage costs do so. This is because atmospheric concentrations are expected to rise and damage costs are expected to be convex in temperature (i.e. there is increasing marginal damage); these effects are assumed to outweigh the declining marginal impact of the stock of gases on global temperature at higher temperatures.

The price of carbon should reflect the social cost of carbon. In any given year, abatement will then occur up to this price, as set out in the right-hand panel of the diagram above. Over time, technical progress will reduce the total cost of any particular level of abatement, so that at any given price there will be more emission reductions.

The diagram reflects a world of certainty. In practice, neither climate-change damages nor abatement costs can be known with certainty in advance. If the abatement-cost curve illustrated in the right-hand panel were to fall persistently faster than expected, that would warrant revising the stabilisation goal downwards, so that the path for the social cost of carbon in the left-hand panel would shift downwards.

Delay in taking action on climate change will increase total costs and raise the whole trajectory for the social cost of carbon. The difference between the social cost of carbon on the 'business as usual' trajectory and on stabilisation trajectories reflects the fact that a tonne of greenhouse gas emitted is more harmful and more costly, the higher concentration levels are allowed to go. Delay allows excessive accumulation of greenhouse gases, giving decision-makers a worse starting position for implementing policies.

Box 13.3 The social cost of carbon and stabilisation

Pearce (2005)[20] reports a range of estimates of the social cost of carbon on 'optimal' paths towards stabilisation goals. The approach of Nordhaus and Boyer (2000) is perhaps closest in spirit to ours. They derive an estimate of only \$2.48/tCO_2 (converted to CO_2, year 2000 prices) for 2001-2010. But they have a low 'business as usual' scenario, do not apply equity weighting and use a discount rate of 3%, which is a little higher than our approach would usually imply.

Further work on what social cost of carbon corresponds to potential stabilisation levels is needed. Current studies disagree about the values and use different methods to tie down the trajectory through time. The US CCSP review reports values of \$20/tCO_2, \$2/tCO_2 and \$5/tCO_2 in 2020 for a stabilisation level of 550ppm CO_2e in the three studies covered. Edenhofer et al. report estimates of the social cost of carbon ranging from 0 to around \$12/tCO_2 in 2010 for the same stabilisation level (year 2000 prices). Most of the models reviewed envisage the social cost of carbon rising over time, with the level and rate of growth sufficient to pull through the required technologies and reductions in demand for carbon-intensive goods and services.

Preliminary calculations with the model used in Chapter 6 suggest that the current social cost of carbon with business as usual might be around \$85/tCO_2 (year 2000 prices), taking the baseline climate sensitivity assumption used there, if some account is taken of non-market impacts and the risk of catastrophes, subject to all the important caveats discussed in Chapter 6. But along a trajectory towards 550ppm CO_2e, the social cost of carbon would be around \$30/tCO_2 and along a trajectory to 450ppm CO_2e around \$25/tCO_2e. These numbers indicate roughly where the range for the policy-induced price of emissions should be if the ethical judgements and assumptions about impacts and uncertainty underlying the exercise in Chapter 6 are accepted.

It would only make sense to have chosen a 550ppm CO_2e target in the first place if a carbon-price path starting at \$30/tCO_2 had been judged likely to be sufficient (together with other policies) to pull through over time the deployment of the technological innovations required. Similarly, it would only make sense to have chosen a 450ppm CO_2e target if a price path starting at \$25/tCO_2e had been judged sufficient to bring through the technology needed.

The social cost of carbon[21] can be used to calculate an estimate of the benefits of climate-change policy. The gross benefits of policy for a particular year can be approximated by

$$(SCC_H \times E_H) - (SCC_S \times E_S)$$

where SCC denotes the social cost of carbon, E the annual level of emissions, the subscript H the high 'business as usual' trajectory and the subscript S the stabilisation trajectory[22]. This is the net present value of the flow of damages from emissions on the high path less the net present value of the flow of damages on the lower path. With sensible policies ensuring that marginal abatement costs equal the social cost of carbon along the stabilisation trajectory, and assuming for simplicity's sake that marginal abatement cost is equal to average abatement cost[23], the annual costs of abatement can be approximated by

$$SCC_S \times (E_H - E_S)$$

Hence benefits less costs are equal to

$$(SCC_H \times E_H) - (SCC_S \times E_S) - (SCC_S \times (E_H - E_S)) = (SCC_H - SCC_S) \times E_H$$

Thus an approximation of the net present value of the benefits of climate-change policy in any given year can be obtained by multiplying 'business as usual' emissions by the difference between the social costs of carbon on the two trajectories. Calculations for this Review suggest that the social cost of carbon on a reasonable stabilisation trajectory may be around one-third the level on the 'business as usual' trajectory, implying that the net present value of applying an appropriate climate-change policy this year might be of the order of \$2.3 – 2.5 trillion. This is not an estimate of costs and benefits falling in this year, but of the costs and benefits through time that could flow from decisions this year; many of these costs and benefits will be in the medium- and long-term future. It is very important, however, to stress that such estimates reflect a large number of underlying assumptions, many of which are very tentative or specific to the ethical perspectives adopted.

[20] Pearce (2005)

13.10 The role of adaptation

Adaptation as well as mitigation can reduce the negative impacts of future climate change.

Adaptation reduces the damage costs of climate change that does occur (and allows beneficial opportunities to be taken), but does nothing direct to prevent climate change and is in itself part of the cost of climate change. Mitigation prevents climate change and the damage costs that follow. Stabilisation at lower levels would entail less spending on adaptation, because the change in climate would be smaller. That needs to be taken into account when considering how total costs change with changes in the ultimate stabilisation level. Similarly, for lower stabilisation levels, a given increase in spending on adaptation is likely to have a bigger effect in lowering the costs of climate change than the same increase at higher concentration levels (because of declining returns to scale for adaptation activities)[24].

There are important differences between adaptation and mitigation that differentiate their roles in policy.

First, while those paying the costs will often capture the benefits of adaptation at the local level, the benefits of mitigation are global and are experienced over the long run. Second, because of inertia in the climate system, past emissions of greenhouse gases will drive increases in global mean temperature for another several decades. Thus mitigation will have a negligible effect in reducing the cost of climate change over the next 30-50 years: adaptation is the only means to do so.

Adaptation can efficiently reduce the costs of climate change while atmospheric concentrations of greenhouse gases are being stabilised.

A stabilisation goal facilitates adaptation by allowing a better understanding to develop of what ultimately societies will have to adapt to. Work using Integrated Assessment Models (IAMs, discussed in Chapter 6) has identified significant opportunities to reduce damage costs through adaptation. There are many reasons other than assumptions about adaptation why the predictions of one model differ from another[25]. It is nevertheless intuitive that those models with the most comprehensive adaptation processes estimate the lowest damage costs and highest adaptation benefits[26]. Studies at a more local level of the costs and benefits of adaptation usually point to net benefits, so some is likely to take place, although policy measures are often required to overcome barriers (see Part V). Adaptation will have a particular role to play in low-income regions, where vulnerability to climate change is higher. In such regions, there are strong complementarities between development policies in general and adaptation actions in particular.

There are further examples of complementarities:

- Mitigation reduces the likelihood of dangerous climate change, which makes adaptation either infeasible or very costly;
- Mitigation reduces uncertainty about the range of possible climate outcomes requiring adaptation decisions. Uncertainty is a clear impediment to successful adaptation.

[21] The social cost of carbon has to be expressed in terms of some numeraire. Typically the change in consumption that brings about the same impact on the present value of expected utility is used. But that depends on the level of consumption one starts with, so the numeraire differs when comparing significantly different paths. Hence these calculations are strictly valid only if consumption along one or other of the two paths (or some weighted average) is used as numeraire for the calculation of both SCCs.
[22] Because the social cost of carbon is a function of the stock of greenhouse gases, not the flow of emissions, it is insensitive to the variation of emissions in a single year.
[23] This is equivalent to assuming constant returns to scale in abatement over time. In fact, we would expect the average abatement cost to be lower than the marginal abatement cost, with dynamic returns to scale reducing them over time, so this simplification gives an underestimate of the benefits of climate-change policy.
[24] Part V considers adaptation in detail. The key point here is that adaptation is likely to become more expensive and less effective as global temperatures rise further.
[25] Hanemann (2000).
[26] In particular, Mendelsohn et al. (2000).

In the longer run, both adaptation and mitigation will be required to reduce climate-change damage in cost-effective and sustainable ways.

They should not be regarded as alternatives. Part II outlined why the damage costs of climate change are likely to increase more rapidly as global mean temperatures increase. As Part V explains in more detail, attempts at adaptation would not be an adequate response to the pace and magnitude of climate change at high global mean temperatures compared with pre-industrial levels. Ecosystems, for instance, cannot physically keep pace with the shifts in climatic conditions implied. The adaptation that remains viable is likely to be very costly. Without mitigation, little can reduce the underlying acceleration in climate-change impacts as temperatures rise. This is why promoting development in developing economies, while vital in its own right and helpful in building the capacity to adapt, is not an adequate response by itself. Mitigation is the key to reducing the probability of dangerous climate change, given the scale of the challenge. A strategy of mitigation plus adaptation is superior to 'business as usual' plus adaptation, and requires less spending on adaptation.

13.11 Conclusions

This chapter has considered in broad terms what climate-change policy should aim to achieve, given the evidence about the risks of serious damages from climate change and the costs of cutting greenhouse-gas emissions. The first priority is to strengthen global action to slow and stop human-induced climate change and to start undertaking the necessary adaptation to the change that will happen before stability is established. The benefits of doing more clearly outweigh the costs. Delay would entail more climate change and eventually higher costs of tackling the problem. The nature of the uncertainties in the science and economics warrants more action not less.

Once the case for stronger global action is accepted, the question arises, how much? We have argued the merits of organising the discussion of this problem around the idea of a goal for the ultimate concentration of greenhouse gases in the atmosphere. Choosing a specific level or range for such a goal should help to make policies around the world more consistent, coherent and cost-effective. In particular, choosing a goal helps to define and anchor a path for the carbon price, a key tool for implementing climate-change policy. The next part of this Review examines in more detail the types of policy instruments that need to be used to reduce greenhouse-gas emissions cost-effectively and on the scale required.

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