



Australian Government  
Productivity Commission

# The Stern Review: an assessment of its methodology

Staff Working Paper

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# Preface

This paper presents what was originally an Internal Research Memorandum to inform the Commission about the methodological underpinnings of *The Stern Review*.

However, with recent policy initiatives in Australia, including the review headed by Professor Ross Garnaut, it became evident that there were benefits in making the work more generally available in a published Staff Working Paper. The paper benefited from feedback received at two Productivity Commission seminars.

The authors acknowledge the constructive comments made by Dean Parham throughout the course of preparing the initial memorandum. Thanks are also due to Neil Byron, Bernie Wonder, Jonathan Pincus, Michael Kirby, Mark Harrison and Greg Murtough for their comments.

The views expressed in this paper remain those of the authors and do not necessarily reflect the views of the Productivity Commission or the Australian Government.

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# Abbreviations and explanations

BAU	business-as-usual
BGE	balanced growth equivalent
CCSP	Climate Change Science Program
CDM	Clean Development Mechanism
CO <sub>2</sub>	carbon dioxide
CO <sub>2</sub> e	carbon dioxide equivalent
EMF	Energy Modelling Forum
GDP	gross domestic product
GHG	greenhouse gas
Gt	gigatonnes
IAM	integrated assessment model
IEA	International Energy Agency
IMCP	International Modelling Comparison Project
IPCC	Intergovernmental Panel on Climate Change
OCC	opportunity cost of capital
ppm	parts per million
R&D	research and development
RTP	rate of time preference
SRES	Special Report on Emissions Scenarios
SRTP	social rate of time preference
TAR	Third Assessment Report
UNFCCC	United Nations Framework Convention on Climate Change



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# Summary

‘The Stern Review: The Economics of Climate Change’, released in October 2006, immediately captured the attention of governments, policymakers and the public. Not only has the Review had a profound impact of itself, its proximity to the subsequent roll-out of the Intergovernmental Panel on Climate Change’s (IPCC) fourth assessment report further fuelled calls for strong collective and national action to address climate change.

The Review’s central message is that climate change is a serious threat to human welfare that demands urgent global action now. It warns that climate change has the potential to lead to major economic and social disruption — on a scale similar to the world wars and the great depression — later in this century and beyond. The Review contends that:

- the costs of climate change will be equivalent to losing between 5 per cent and 20 per cent of global GDP each year, now and forever
- the costs of reducing greenhouse gas (GHG) emissions to avoid the worst climate change impacts could be limited to 1 per cent of global GDP each year.

The Review’s estimates of future economic damages are substantially higher, and its abatement costs lower, than most earlier studies. In contrast to the Review’s call for immediate action, earlier studies generally had concluded that optimal policy responses involve modest reductions in GHG emissions in the near term with subsequent sharper reductions in the longer term. Stern (in a postscript to the Review) identified four key differences between his approach and that of other studies. Specifically, the Review:

1. Draws on recent science which points to ‘significant risks of temperature increases above 5°C under business-as-usual by the early part of the next century’ — other studies typically have focused on increases of 2–3°C.
2. Treats aversion to risk explicitly.
3. Adopts low pure time discount rates to give future generations equal weight.
4. Takes account of the disproportionate impacts on poor regions.

The Review provides a comprehensive and systematic analysis of the costs and benefits of taking action (or failing to take action) to reduce GHG emissions.

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Conventional economic analysis lies at its heart, guided by assumptions and methodologies that reflect the authors' views about the need to avert the risk of worse than expected outcomes — climatic catastrophes at the tail of the probability distribution. Indeed, the prospect of higher than expected temperature rises appears to condition the Review's approach to (1) risk aversion, (2) the choice of discount rates and (3) its judgements about appropriate equity weightings. The choice of discount rates, however, is the prime reason why the Review's estimates diverge from those of other studies.

The Review's 'urgent' language can be explained by it being as much an exercise in advocacy as it is an economic analysis of climate change. It is not surprising, therefore, that reaction to it has been mixed. It has been:

- hailed as establishing the case for strong action now to reduce GHGs
- welcomed for identifying the need for action but criticised for overstating the case for a strong, immediate response
- disparaged as an alarmist polemic based on extreme positions on critical economic parameters.

Among these divergent views, however, is general agreement about the analytical challenges posed by the pervasive scientific, economic and geo-political uncertainties associated with climate change. Rarely do analysts confront cost-benefit analyses with dimensions so long-term, uncertain and non-marginal. This places extraordinary strains on analytical techniques that generally have been devised for more conventional projects, and almost inevitably means that value judgements and ethical perspectives become more prominent.

## **The foundation — Stern and the climate change science**

The Review simulates temperature estimates for 'baseline' climate and 'high' climate scenarios, with the latter aiming to capture effects if temperature is pushed higher by amplifying feedbacks — such as weakened carbon sinks and increases in natural methane releases. For the baseline scenario, the Review estimates that the global average temperature will increase between 2.4 and 5.8°C by 2100, relative to the pre-industrial era (90 per cent probability). The estimate for the high scenario is 2.6–6.5°C.

It is informative to compare the Review's estimates with those subsequently projected by the IPCC. While the IPCC provides projections for six 'emissions marker scenarios' (noting that all are equally valid), the Review's projections for

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both its baseline and high climates are based on one scenario — which is associated with high range GHG emissions.

The Review's temperature projections are consistent with those of the IPCC's high emissions marker scenarios, but higher than the IPCC's other scenarios. Notwithstanding this consistency, the Review tends to lead with headline messages that incorporate lower probability outcomes and hence it elevates more adverse climate change consequences than does the IPCC. For example, the first chapter of the Review asserts that if annual GHG emissions remain at current levels until 2100, the world will be committed to warming of 3–10°C — the upper end of which is well outside the 'likely' range in the IPCC's fourth assessment report.

## **Estimating climate change damage costs**

The Review's approach to analysing the impacts of climate change is twofold.

1. It engages in a lengthy qualitative discussion of the impacts of climate change on water availability, sea levels, biodiversity, food production and human health. No monetary values are ascribed to impacts in this bottom-up analysis.
2. Overall damage estimates are derived using an Integrated Assessment Model, PAGE2002. The model deals with uncertainty through a 'Monte Carlo' simulation. Each scenario is run 1000 times with parameters chosen at random from the ranges given in the climate change literature, yielding a probability distribution of damage cost estimates (GDP losses).

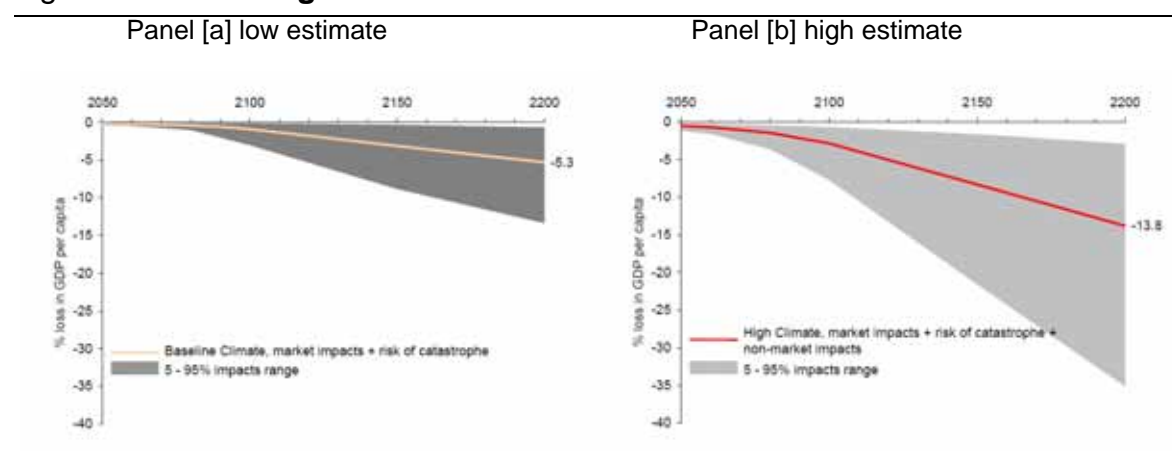
In relation to the bottom-up analysis, the literature on the impacts of climate change varies widely. For example, some emphasise the beneficial impacts for some regions (for example, through the carbon fertilisation effect), although such benefits are expected to dissipate at higher temperatures. Although the Review acknowledges the controversies and uncertainties of impact assessments, it draws heavily on studies that have a more pessimistic view on climate change and its impacts, and gives little attention to more optimistic views.

The damage cost estimates assume that developing countries continue to have an elevated vulnerability to climate change damage even after per capita incomes increase substantially. That is, it does not systematically take into account the potential of adaptation measures to reduce damages and of social and economic development to reduce vulnerability to climate change. The estimates are also based on population growth projections that are much higher than those of leading bodies, such as the United Nations.

Accordingly, the Review’s results are at the upper end of the range of the literature. Apart from any tendency to draw on the more pessimistic damages literature, another reason for this is methodological. The Review attempts a more complete coverage of damage costs than most previous studies, which have tended to confine analysis to market impacts only. The Review incorporates non-market costs — which is methodologically sound but relies on ‘rough and ready’ estimates — and also the risk of abrupt, large-scale climate change. Appropriately, in the main body of the report at least, the Review presents the results for these impact categories separately, thereby arming decision makers with information to take account of the respective uncertainties.

The Review estimates the mean damage costs (for the low estimate), including the risk of catastrophe, at 5.3 per cent of global GDP in 2200, with a 10 per cent probability that damage costs are either less than 1 per cent or over 12 per cent of GDP (figure 1 [a]). The low estimate is based on the middle set of impact categories (market impacts plus the risk of catastrophe) and the baseline climate scenario.

Figure 1 **Damage costs**



Source: Stern (2006).

Adding non-market impacts and changing to the high climate scenario yields a high estimate of damage costs with a mean of 13.8 per cent of GDP in 2200 (figure 1 [b]) and a correspondingly higher range of uncertainty.

## Estimating climate change mitigation costs

In the climate change literature, two basic approaches are used to estimate mitigation costs: resource costs and macroeconomic modelling. The resource cost approach uses costs of individual emission-saving measures to estimate mitigation costs — a ‘bottom-up’ approach. Macroeconomic modelling of mitigation explores

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the economywide effects of the transition to a lower emissions economy — a ‘top-down’ approach. The Review pursues both approaches.

The resource cost estimate carries a large degree of uncertainty and this is acknowledged. For the central estimate of mitigation costs of 1 per cent of GDP, a range from -1 per cent to 3.5 per cent is given. This reflects the sensitivity of the estimates to assumptions about technological change.

The Review claims that the resource cost estimate is an upper bound estimate of costs. This is not necessarily the case because other effects, such as feedbacks between the energy sector and the rest of the economy which could lead to higher costs, are ignored by resource cost estimates. Further, assumptions about the efficiency of policy and technological change may turn out to be too optimistic.

The macroeconomic modelling estimates are based on meta-analyses of a range of models. The Review estimates the annual costs of stabilisation at 500–550 ppm carbon dioxide equivalent to be around 1 per cent of global GDP in 2050 (with a range of +/-3 per cent), and likely to remain around this level after 2050. This is at the low end of the range of estimates in the literature, largely because of a reliance on models that assume technological change will be induced by policy action. This may be theoretically sound but, in practice, is difficult to model reliably. Moreover, other model comparison studies suggest that costs are likely to increase as a proportion of GDP after 2050.

## **Aggregating the damages and mitigation costs**

The Review aggregates the estimated climate change damage costs and the mitigation costs to give all inclusive estimates. The aggregation involves difficult and contentious areas such as discounting, dealing with uncertainty and weighting costs in poorer countries. Inevitably, ethical considerations come into the choice of aggregation factors for climate change and different ethical perspectives lead to very different results and policy prescriptions.

Because mitigation incurs costs now for benefits that are expected mainly in the very long-term future, economists use discounting to bring the costs and benefits to a common timeframe. The choice of discount rates is critical. The Review’s headline conclusion that business-as-usual emissions involve costs and risks that are equivalent to losing 5 per cent to 20 per cent of global GDP, now and forever, is based on discount rates that appear to be around 1.4 per cent per annum. These low rates are the main reason the Review’s headline estimates of damage costs are so much higher than most other studies — many times higher than the estimates of

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Nordhaus and other prominent economists. Adding 1 percentage point to the discount rates reduces the damage cost estimates by more than half.

While it is not possible to say whether the Review's approach to discounting is definitively right or wrong, some conclusions can be drawn:

- The Review's approach is based on ethical judgements about intergenerational equity that are not necessarily representative of wider opinion and certainly are different from the judgements of some other climate change analysts.
- Under the Review's approach, community wellbeing is said to be increased by forgoing current consumption in order to make climate-related investments that produce benefits in the long term. Whether these investments are superior to alternative investments is left unanswered by the analysis.
- Basing discount rates on market interest rates, as others do, tends to guard against the adoption of sub-optimal investments. For some, however, the outcomes of this approach can raise concerns about intergenerational equity.
- Some analysts start with the presumption that discount rates used for estimating the costs of climate change need to be low, because very long-term environmental effects should not be trivialised through strong discounting. However, to the extent that these concerns are valid, they are best addressed by varying environmental valuations over time, not by altering the discount rate.

Regardless of the different views about discounting, the Review erred in its failure to present a range of results for different discount rates. Stern did provide a limited sensitivity analysis belatedly in a postscript to the Review, although the highest parameter values included equate to discount rates that are still relatively low.

The Review also compares estimates of total damage costs with mitigation costs. This is not entirely appropriate. Mitigation costs should be compared with the damage costs they are expected to avoid to facilitate an assessment of the net benefits from action. However, because the difference between total and avoided damage costs is not large, this 'asymmetry' does not make a material difference to the Review's conclusions.

## **Climate change policy**

Based on its analysis of costs, benefits and risks, the Review calls for strong, early action on mitigation. It outlines three essential elements of policy for mitigation.

- An emissions price, preferably equalised across countries, achieved through tax, trading or regulation.

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- Support for the development of a range of low-carbon technologies.
  - Removal of barriers to behavioural change, particularly to encourage the uptake of opportunities to improve energy efficiency.

The Review is not prescriptive about the choice of policy instruments. This may reflect pragmatic considerations about the importance of building a coalition for action by not dictating options that might be politically infeasible in some countries.

The Review places most emphasis on emissions pricing, stressing the importance of environmental effectiveness, efficiency, cost-effectiveness, credibility, flexibility and predictability.

It acknowledges that, in the absence of any other market failures, a credible emissions price path should be sufficient to encourage suitable technologies. However, it contends that such conditions do not hold in practice for various reasons — for example, innovation produces public spillover benefits that may lead to it being undersupplied privately.

Accordingly, the Review advocates policies to bring a portfolio of low-emission technologies to commercial viability. While advocating governments be cautious about ‘picking winners’, the Review identifies energy storage, photovoltaics, biofuel conversion, fusion, material science and carbon capture and storage as having potential. It also advances arguments for government support for deployment of low-emissions technologies through subsidies, quota-based schemes and price support mechanisms. Notwithstanding the potential for spillover benefits, the emphasis given to deployment support is surprising given the potential for this to increase mitigation costs unnecessarily.

Further, the Review proposes that, even if emissions pricing and technology support measures are introduced, market imperfections may inhibit some low-cost action. For example, households and firms may not take up energy efficiency opportunities even when it would be cost effective. Proposed measures to address such barriers include: minimum energy performance standards and integrated land-use planning to reduce transport demand.

The Review finds that preventing deforestation can be a low-cost means of reducing emissions. While incentives for this could be achieved within emissions trading markets, the Review contends that this could destabilise these markets.

The Review acknowledges that adaptation is the only way to deal with the unavoidable impacts of climate change. Although it argues that mitigation and adaptation should go ‘hand-in-hand’, it does not discuss an integrated policy framework.

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The Review does not lay out a ‘blueprint’ for collective action, but rather outlines desirable features for an international framework. It identifies faults of the Kyoto Protocol, but suggests building on this framework. It considers that the post-2012 framework should be based around binding emissions caps for individual countries that can be met in part through international trading in emission permits. This position is not universally held. Others, for example, contend that: there should be no nexus between country-based caps and an overall target; international trading in permits is undesirable; and an internationally harmonised tax on emissions is preferable to a cap-and-trade architecture.

The issue that most dominates the geo-political debate, however, is the treatment of developing countries. Most developing countries have ratified the Kyoto Protocol but are not required to take on binding emissions targets. Under the Protocol’s Clean Development Mechanism, developed countries may earn credits towards meeting their targets by implementing projects in developing countries.

The Review argues that, in the long term, developing countries must incorporate the externalities of using carbon into the structure of incentives in their own economies. However, it appears to support the continued use of the Clean Development Mechanism for a considerable period of time. It further suggests that if mitigation costs were 1 per cent of GDP, rich countries might, for equity reasons, pay 1.2 per cent and poorer countries 0.2 per cent in the initial decades. This could involve rich countries investing in emission reduction activities outside their own borders. Other analysts have suggested ways that developing countries could take on binding targets without imposing high costs in the short term.

## **The Review’s contribution**

One indicator of the Review’s contribution can be gauged from the reaction of its staunchest critics. Initially, some critics were strident in their claims that the Review was a biased and alarmist polemic. More recently, some of these criticisms have become more muted. There appears to be an emerging view that the Review has made a valuable contribution by establishing climate change as an economic issue that can be assessed through the ‘lens’ of a cost–benefit framework.

Moreover, the Review team continues to engage with its critics and to expose its work (including rebuttals of critiques) to scrutiny. In some instances, its responses indicate acceptance of criticisms levelled. In this respect the Review continues to be important as a catalyst for engendering further analysis, development and refinement of the economics of climate change.



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Methodologically, a strength of the Review is that it attempts to move beyond an analysis based on the expected (or ‘mean’) outcome to one that incorporates low probability, but potentially catastrophic, events at the tail of probability distributions. Indeed the Review is the first cost–benefit analysis of climate change to incorporate formally such potential outcomes in such an integrated way in its modelling. Also to its credit, the Review uses top-down as well as bottom-up estimation procedures in its derivation of damage and mitigation costs — although in the former case, the bottom-up approach appears to be primarily a vehicle for delivering selected sobering views about the potential impacts of climate change on human welfare.

Some of the criticisms of the Review are justified. The assertiveness with which some of the headline messages are delivered is not always matched by the caution attached to the evidence and analysis presented within the body of the report. And, relevant questions remain about the way the analysis was focused. It is based on a single high emissions scenario, inclines towards more pessimistic assumptions on damage costs, and adopts unconventional parameters for discount rates. These traits tend to escalate the present value of future costs and thereby elicit urgency in mitigation measures.

This is consistent with the Review authors’ apparent belief that, although catastrophic outcomes may be unlikely, the implications for future generations, were they to arise, would be so detrimental that it would be remiss to fail to give them sufficient weight. There is nothing especially wrong with this view — as one critic has conceded, the Review’s conclusions may well be proved right but for the wrong reasons. However, the Review presents itself to decision makers as yielding conclusions underpinned by conventional, rational economic analysis. In fact, the authors’ concerns about catastrophe in conjunction with their attendant ethical perspectives, permeate many stages of the analysis. More sensitivity analysis to highlight the consequences of alternative views and value judgements would have been valuable.

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# 1 Introduction

*The Stern Review: The Economics of Climate Change* (hereafter the Review), produced under the direction of the United Kingdom (UK) Cabinet Office and the UK Treasury was launched by the Prime Minister and the Chancellor of the Exchequer in October 2006. The Review was headed by Sir Nicholas Stern, (at the time) Head of the Government Economic Service and Adviser to the British Government on the economics of climate change. The central message of the Review is that:

... if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5 per cent of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20 per cent of GDP or more. In contrast, the costs of action – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1 per cent of global GDP each year. ... So prompt and strong action is clearly warranted. ...

If no action is taken to reduce emissions, the concentration of greenhouse gases in the atmosphere could reach double its pre-industrial level as early as 2035, virtually committing us to a global average temperature rise of over 2°C. In the longer term, there would be more than a 50 per cent chance that the temperature rise would exceed 5°C. This rise would be very dangerous indeed; it is equivalent to the change in average temperatures from the last ice age to today. (Stern 2007c, p. xv–xvi)

The Review's estimates of economic damages from climate change are substantially higher, and its abatement costs lower, than those in most other studies using similar economic models. And, where the Review calls for strong action now, other studies conclude that optimal policy responses involve modest reductions in greenhouse gases (GHGs) in the near term with subsequent sharper reductions in the longer term — this approach is referred to as the 'climate-policy ramp' (see, for example, Nordhaus 2006b; Kelly and Kolstad 1999).

## 1.1 Reaction to the Stern Review

The Review received worldwide attention and has evoked strong, often polar, responses (box 1.1). Views and counterviews continue to be published in the popular media and in academic journals, eliciting further rounds of critiques and 'postscripts'. Indeed, throughout 2007, the Review team continued to publish work-in-progress papers on its website.

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## Box 1.1 Responses to the Stern Review

### Endorsements (from Nobel Laureates in economics)

If the world is waiting for a calm, reasonable, carefully argued approach to climate change, Nick Stern and his team have produced one. They outline a feasible adjustment policy at tolerable cost beginning now. Sooner is much better. (Robert Solow)

The stark prospects of climate change and its mounting economic and human costs are clearly brought out in this searching investigation. What is particularly striking is the identification of ways and means of sharply minimizing these penalties through acting right now ... The world would be foolish to neglect this ... practical message. (Amartya Sen)

The Stern Review ... provides the most thorough and rigorous analysis to date of the costs and risks of climate change, and the costs and risks of reducing emissions. It makes clear that the question is not whether we can afford to act, but whether we can afford not to act. ... it provides a comprehensive agenda — one which is economically and politically feasible — behind which the entire world can unite ... (Joseph Stiglitz)

The Stern report shows us, with utmost clarity, while allowing fully for all the uncertainties, what global warming is going to mean; and what can and should be done to reduce it. It provides numbers for the economic impact, and for the necessary economic policies. It deserves the widest circulation. (James Mirrlees)

### Criticisms

... the Stern Review is very selective in the studies it quotes on the impacts of climate change. The selection bias is not random, but emphasises the most pessimistic studies. ... The report claims that a cost-benefit analysis was done, but none was carried out. The Stern Review can therefore be dismissed as alarmist and incompetent. (Richard Tol)

The Review's unambiguous conclusions about the need for extreme immediate action will not survive the substitution of discounting assumptions that are consistent with today's market place. So the central questions about global warming policy — how much, how fast, and how costly — remain open. (William Nordhaus)

The rhetoric deployed by the authors ... skims over the fact that we have little intuitive feel for the numerical weights that should be placed on normative parameters. Where the modern economist is rightly hesitant, the authors of the Review are supremely confident. ... the cause isn't served when parameter values are so chosen that they yield desired answers. (Partha Dasgupta)

... the choice of an appropriate policy toward global warming depends heavily on how one weighs the costs and benefits it imposes on different generations. The Stern Review chose a particular way to do this, but many other choices could have been examined. (Hal Varian)

.. far from being an authoritative guide to the economics of climate change, the Review is deeply flawed. It does not provide a basis for informed and responsible policies. (Byatt et al.)

Sources: Stern 2006a, Byatt et al. 2006; Dasgupta 2006; Nordhaus 2006b; Tol 2006; Varian 2006.

The Review has been:

- hailed as establishing the case for strong collective action now to reduce GHGs
- greeted cautiously as identifying the need for action but failing to demonstrate that a strong, immediate response is required — the climate policy ramp debate

- 
- decried as an alarmist polemic based on selective use of science and extreme positions on critical economic parameters.

Some of the contention about the approach adopted in the Review centres on the way it seeks to account for highly uncertain, but potentially catastrophic, outcomes from climate change. Where there is pervasive uncertainty, standard analytical approaches are challenged and value judgements and ethical perspectives, often reflecting people's degree of risk aversion, can come to the fore. For example:

It seems worth a very large premium to insure ourselves against the most catastrophic scenarios. Denying the risk seems utterly stupid. (Carl Wunsch, Massachusetts Institute of Technology, cited in Revkin 2007)

... climate change is real, must be faced and action taken. But the discourse of catastrophe is in danger of tipping society onto a negative ... and reactionary trajectory. (Mike Hulme, Tyndall Centre for Climate Change Research, cited in Revkin 2007)

Such views capture the essence of policy-making under uncertainty.

## **Stern Review — some context**

A key contextual issue centres on the authoritativeness of the Review. Nordhaus (2006b), among others, observes that the Review was published without its methods and assumptions being appraised by independent experts — 'even the analysis of HM Government needs peer review' (p. 5). Others dispute this claim — Anderson (2007), for example, notes that the Review team had exposed much of its work in public papers and seminars prior to publication.

Other commentators allude to a political agenda for the Review noting that, in July 2005, the UK House of Lords Select Committee on Economic Affairs released a report also entitled *The Economics of Climate Change* (House of Lords 2005). That report raised doubts about the rigour and objectivity of the Intergovernmental Panel on Climate Change (IPCC). It contended, for example, that some of the IPCC's emissions scenarios and documentation are influenced by political considerations and that positive aspects of global warming are downplayed. It also criticised the Kyoto Protocol for having a naive compliance mechanism that can only deter countries from signing up to subsequent tighter emissions targets. The UK Government's response (November 2005) to the report was unenthusiastic. It is a matter of conjecture as to whether the UK Government's response to the House of Lords report and the subsequent commissioning of the Review reflected any particular domestic or geo-political motivation.

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Given the policy influence of the Review and the highly divergent views that have accompanied its release, this paper aims to:

- summarise the Review’s methodology, findings and policy prescription
- assess the quality of the economic analysis
- position that analysis within other literature on the economics of climate change.

## 1.2 A global externality

Starting from the IPCC’s consensus position that human activity, by increasing atmospheric concentrations of GHGs, is contributing to climate change (see chapter 2), means that any resultant costs are not paid for by those who create the emissions. In this context, climate change is an externality associated with GHG emissions, but different to other externality problems in its global scale, time dimension and potentially non-marginal impacts. The Review contends that climate change ‘must be regarded as market failure on the greatest scale the world has seen’ (Stern 2007c, p. 27).

Deconstructing elements of this externality — and the implied scientific, economic and geo-political uncertainties — underpins the Review’s concerns. For instance:

- The anthropogenic contribution to climate change is a global problem:
  - all countries have emitted (stock) and continue to emit (flows) of GHGs, but with consequences that will not fall proportionately on them
  - addressing the problem will require a coordinated response involving sovereign states across the spectrum of economic development.
- The impacts of climate change are long-term and persistent:
  - much of the stock of GHG has arisen from the economic progress of developed nations (rich countries), yet much of the anticipated growth in emissions in the future will come from countries embarking on a similar pursuit of economic progress (developing countries)
  - the costs will primarily be borne by future generations — a weak political constituency — implying a need to consider trade-offs between current consumption and future welfare.
- There are pervasive uncertainties about the climate change science, compounded by unknown prospects of ‘worst case’ scenarios:
  - if climate change turns out to be less serious than predicted or a future technology can address it cost effectively, then early action could impose an unnecessarily large burden on near generations

- 
- if action is delayed and the prognosis worsens, opportunities for adopting low-cost abatement measures may have passed, shifting a greater burden onto future generations
  - delaying action might mean that if it belatedly was determined that a low probability catastrophic outcome — such as a ‘runaway’ collapse of the polar ice sheets or extraordinary changes to ocean currents — was likely to arise, this discovery might be made after the critical threshold to avoid such an outcome has passed.

Rarely, if ever, have analysts been confronted with a cost–benefit analysis of dimensions that were so vast, long-term, uncertain and so critical (potentially large-scale species extinction and significant human health impacts). This places extraordinary strains on analytical techniques that generally have been devised for smaller, more manageable projects. The Review adopts a position that ‘uncertainty is an argument for a more, not less, demanding [mitigation] goal’ (Stern 2007c, p. 318).

Faced with pervasive uncertainties, the Review essentially arrives at a view that it is better to incur costs early for uncertain benefits, than to delay action until more is known, because the latter approach carries potential for higher (intergenerational) damage, adaptation and mitigation costs. This is highlighted in a postscript to the Review, where Stern explains that the Review:

1. treats aversion to risk explicitly
2. uses recent science on probabilities which points to ‘significant risks of temperature increases above 5°C under business-as-usual by the early part of the next century’ — other studies typically have focused on increases of 2–3°C
3. adopts low pure time discount rates to give future generations equal weight
4. takes account of the disproportionate impacts on poor regions.

Hence, the critical factors that lead the Review’s conclusions to deviate from those of earlier studies are the adoption of very low discount rates (3) and the position taken on aversion to risk (1 and 2).

### **1.3 Outline of the paper**

The science of climate change is briefly outlined in chapter 2, which discusses the climate change mechanism, the degree of uncertainty and some projected impacts of global warming. Because the science and consequent damage estimates provide the foundation on which the costs and benefits of business-as-usual (BAU) versus abatement responses rest, the chapter comments on the Review’s use of the climate change science.

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Estimates of the costs and benefits of global warming over time are discussed in chapter 3. The strengths and weaknesses of the Review's estimates and the wider literature on damage costs are canvassed.

The costs of reducing GHG emissions below BAU levels are investigated in chapter 4. The chapter analyses the approach adopted by the Review and compares this with the wider literature on mitigation costs.

Aggregation of costs and benefits is considered in chapter 5, which examines the critical issues of time (discounting), risk (degree of risk aversion) and equity weighting. The Review's approach to aggregation is influenced strongly by ethical considerations which are discussed in relation to approaches taken in the wider literature.

Climate change policy is the subject of chapter 6. It discusses policy responses for mitigation and adaptation and also international collective action. The Review's position is compared with views from the wider policy debate.

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## 2 The science of climate change

Climate science involving theory, observation, interpretation and projection provides the basis for estimating the impacts (damage costs) of climate change and hence, the benefits of avoiding climate change-related bio-physical impacts. The Review was not tasked with undertaking a scientific evaluation of climate change, but the manner in which it incorporates the science is pertinent.

This chapter commences with an overview of the ‘greenhouse effect’ and the Intergovernmental Panel on Climate Change’s (IPCC’s) appraisal of the links between human activity and climate change, including its fourth assessment report (IPCC 2007a,b,c). The approach adopted in this paper is to accept the views of the IPCC as authoritative, while acknowledging that such views are very widely, but not universally, accepted.

### 2.1 The greenhouse effect

The Earth’s atmosphere is composed mainly of nitrogen, oxygen and argon — gases with limited interactions with incoming solar radiation and outgoing infrared radiation. Other gases such as carbon dioxide (CO<sub>2</sub>), methane, nitrous oxide and ozone are known as greenhouse gases (GHGs) because they absorb and emit infrared radiation. These GHGs make up less than 0.1 per cent of the dry atmosphere. The atmosphere also contains water vapour which is the most abundant GHG at around 3000 parts per million (ppm).

GHGs absorb outgoing infrared radiation emitted by the Earth’s surface, the atmosphere and clouds, and emit infrared radiation in all directions, including back to the Earth’s surface. By trapping heat within the atmosphere, these gases create a natural greenhouse effect, part of the Earth’s energy balance, that makes the planet habitable (figure 2.1).

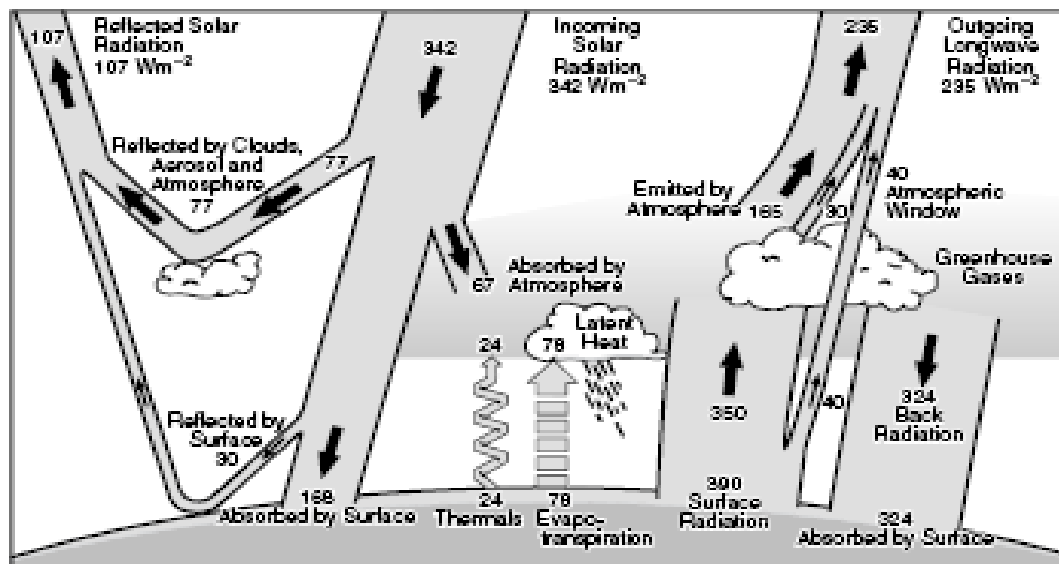
#### The enhanced greenhouse effect

Higher concentrations of GHGs increase the emission and absorption of infrared radiation. As concentrations rise, outgoing infrared radiation is reduced and the temperature of the surface-troposphere system increases. It is believed that the overall effect of ‘feedbacks



effects' (some negative, others positive)<sup>1</sup> is to amplify any temperature increase, but with uncertainty about the effect of clouds.

Figure 2.1 The Earth's global and mean energy balance<sup>a</sup>



<sup>a</sup> Of the incoming solar radiation, 49 per cent ( $168\text{Wm}^{-2}$ ) is absorbed by the surface. That heat is returned to the atmosphere as sensible heat (heat that can be sensed), as evapotranspiration (latent heat) and as thermal infrared radiation. Most of this is absorbed by the atmosphere, which in turn emits radiation both up and down. The radiation lost to space comes from cloud tops and atmospheric regions much colder than the surface.

Source: IPCC (2001c), reproduced from Kiehl and Trenberth (1997).

The IPCC reports that atmospheric concentrations of  $\text{CO}_2$  have increased at an unprecedented rate since pre-industrial times and continue to rise (figure 2.2):

Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. (IPCC 2007c, p. 2)

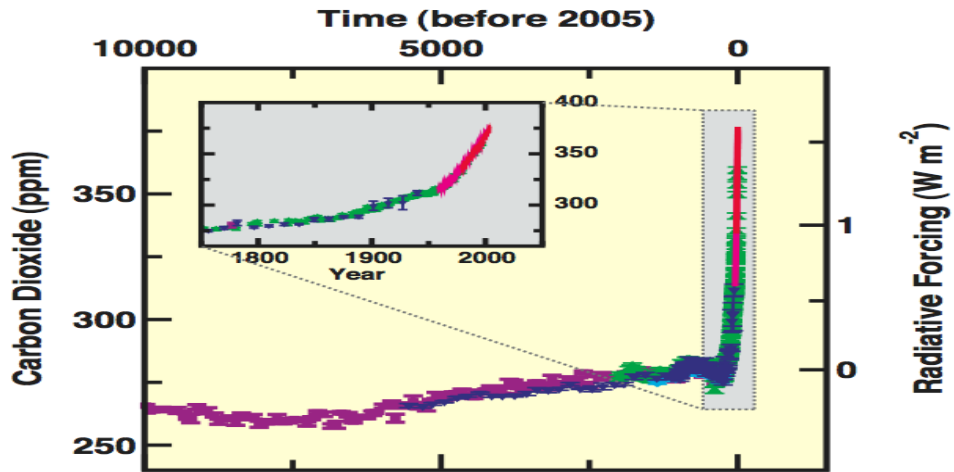
Changes in global average temperatures from 1850-2005 are shown in figure 2.3. The long-term temperature record, shown in figure 2.4, highlights the degree of volatility over the last 400 000 years.

Summarising the science, it is universally accepted that since the pre-industrial era:

- emissions and atmospheric concentrations of GHGs have increased
- the Earth has warmed by around  $0.7^\circ\text{C}$
- human activity has contributed to higher atmospheric concentrations of GHGs.

<sup>1</sup> An increase in water vapour caused by higher temperatures is a key feedback thought to amplify any temperature increase. The effect of increasing aerosols is not well understood but it is believed that, by scattering incoming solar radiation, they offset the enhanced greenhouse effect.

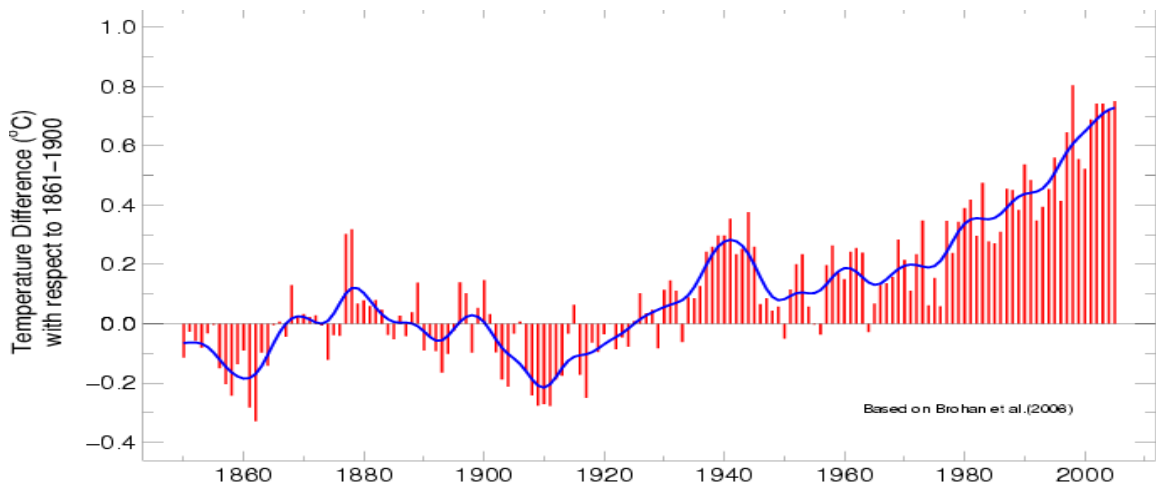
Figure 2.2 **Changes in carbon dioxide concentrations<sup>a</sup>, <sup>b</sup>**  
Based on ice core and modern data



**a** CO<sub>2</sub> is the most important anthropogenic greenhouse gas. The atmospheric concentration of CO<sub>2</sub> has increased from a pre-industrial value of about 280 parts per million (ppm) to 379 ppm in 2005. The annual CO<sub>2</sub> concentration growth rate from 1995–2005 averaged around 1.9 ppm per year, compared with an average of 1.4 ppm per year for the period 1960–2005. **b** Radiative forcing, shown on the right axis, is a measure of the influence that a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism.

Source: IPCC (2007c).

Figure 2.3 **Global average near surface temperatures 1850-2005**

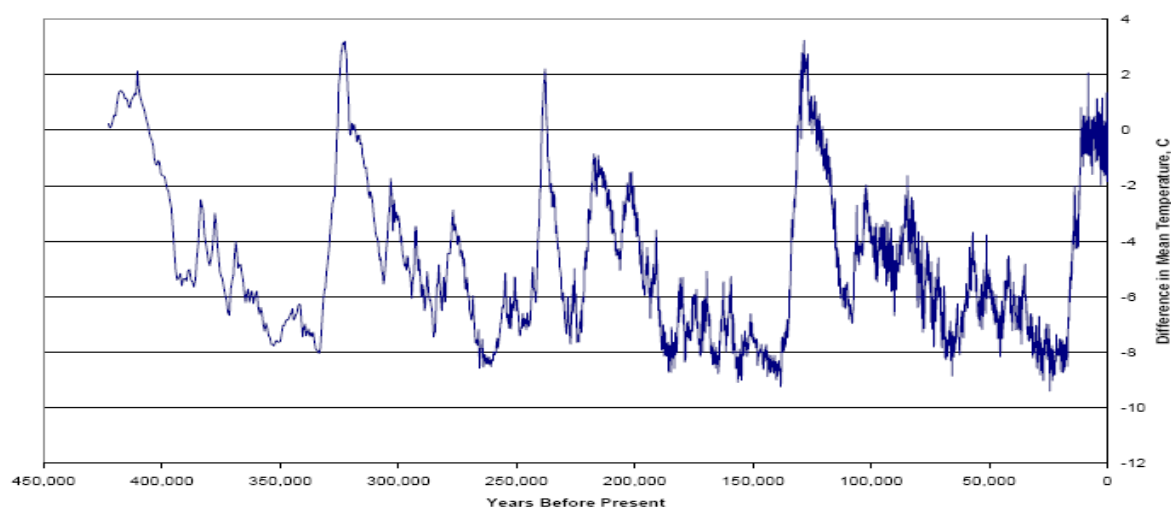


Source: Stern (2007c).

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Figure 2.4 Global temperature record, Vostok ice core data

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Source: McKibbin (2007).

There is an emerging consensus that anthropogenic emissions have already caused the Earth to warm. In 1995, the IPCC observed that the ‘balance of evidence suggests a discernible human influence on global climate’ (IPCC 1995, p. 1). By 2001, it considered that this influence was ‘likely’ and in February 2007, reported that most of the observed increase in temperatures was ‘very likely’ due to increases in anthropogenic GHG emissions.<sup>2</sup>

### The IPCC’s probabilities for future states

Projections of the impacts of higher atmospheric concentrations of GHGs are based on climate models, which approximate dynamic systems. Many climate forcings (positive and negative) — such as aerosols, clouds and oceans — are not well understood. As the IPCC noted in its third assessment report:

In climate research and modelling, we should recognise that we are dealing with a coupled non-linear chaotic system, and therefore that the long-term prediction of future climate states is not possible. The most we can expect to achieve is the prediction of the probability distribution of the system’s future possible states by the generation of ensembles of model solutions. (IPCC 2001c, p. 774)

As well as the scientific uncertainty, there is uncertainty about how human populations and economies will develop, and therefore what business-as-usual GHG emissions would be.

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<sup>2</sup> ‘Likely’ equates to a greater than a 66 per cent probability of occurrence and ‘very likely’ a greater than 90 per cent probability. These probabilities reflect a consensus judgement. The IPCC has two higher probability standards — ‘extremely likely’ and ‘virtually certain’ (IPCC 2007c).

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To deal with this uncertainty, the IPCC presents results for a range of ‘emissions marker scenarios’. These scenarios are described in box .

**Box 2.1 The main characteristics of the IPCC scenarios**

The IPCC has developed four scenario families (A1, A2, B1 and B2). The A1 scenario family contains three variants and so in total there are six emissions marker scenarios.

The A1 scenario family describes a future world of rapid economic growth, global population that peaks mid-century and declines thereafter, and the rapid introduction of more efficient technologies. A major underlying theme is a substantial reduction in regional differences in per capita income. The A1 family includes three alternative directions of technological change in the energy system: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) — defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies.

The A2 scenario family describes a heterogeneous world of self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Per capita economic growth and technological change are more fragmented and slower than other storylines.

The B1 scenario family describes a convergent world with the same global population over time as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies.

In the B2 scenario family the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines.

*Source:* IPCC (2000).

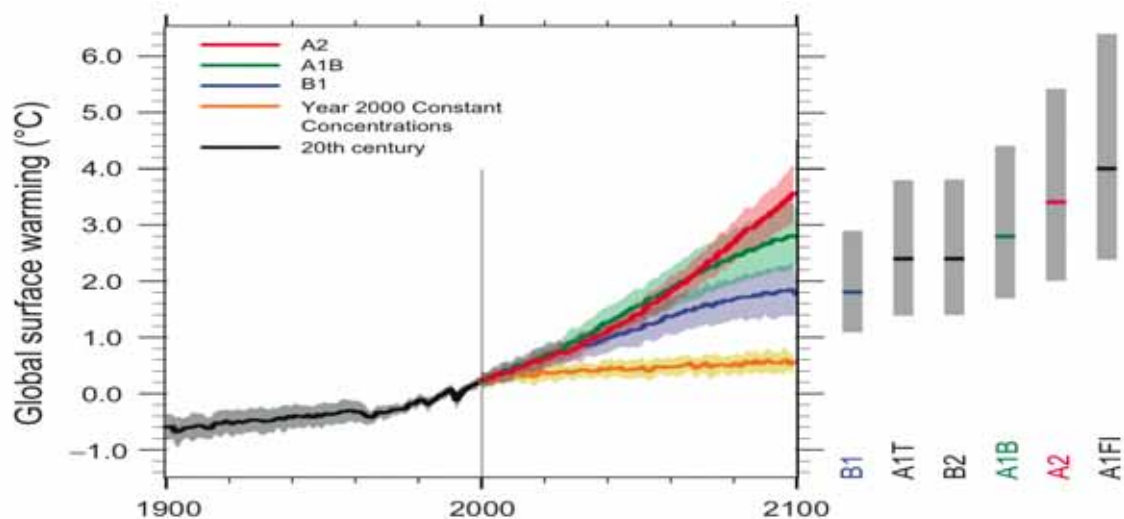
In its most recent assessment, the IPCC reported global warming projections to 2100 for the various scenarios (figure 2.5). It stated:

Best estimates and *likely* ranges for globally average surface air warming for six ... emissions marker scenarios are given in this assessment ... For example, the best estimate for the low scenario (B1) is 1.8°C (*likely* range is 1.1°C to 2.9°C), and the best estimate for the high scenario (A1FI) is 4.0°C (*likely* range is 2.4°C to 6.4°C). (IPCC 2007c, pp. 13-14)

The IPCC further projected that, if radiative forcing were to be stabilised in 2100 at A1B levels, thermal expansion would lead to 0.3 to 0.8 m of sea level rise by 2300 (relative to 1980–1999). Moreover, it stated that contraction of the Greenland ice sheet would continue to contribute to sea level rise after 2100. Climate models suggest that, as temperature rises, ice mass losses increase more rapidly than gains due to precipitation. This balance is thought to become negative at a global average warming (relative to pre-industrial levels)

in excess of 1.9 to 4.6°C. Accordingly, if a negative balance were sustained for millennia, the Greenland ice sheet would be eliminated, leading to a sea level rise of about 7 metres (IPCC 2007c).

Figure 2.5 **Multi-modal averages and assessed ranges for global warming**



**a** Solid lines are multi-model global averages of surface warming (relative to 1980-99) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the +/- 1 standard deviation range of individual model annual averages. The lower (orange) line shows concentrations held at year 2000 values. The bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios.

Source: IPCC (2007c).

It is important to recognise that in making climate projections there is a need to contend with uncertainty about:

- the precise extent of the relative contributions of human activity and natural phenomena to warming<sup>3</sup>
- the degree of climate sensitivity to different GHG concentrations
- the effects of temperature changes on natural and human systems — particularly at regional levels
- the timing and severity of climate change.

Continuing research seeks to reduce uncertainty by, for instance, improving understanding of feedback effects.

<sup>3</sup> While the IPCC (2007c) has ‘very high confidence’ that the net effect of human activity since 1750 has been one of warming, there is a low to medium assessed level of scientific understanding for most anthropogenic radiative forcing components and a low level of scientific understanding for solar irradiance.

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Some of the burgeoning climate change literature suggests higher probabilities of catastrophic outcomes — for example, ‘tipping points’ leading to a Gulf stream collapse. Other literature, however, contends that the influence of GHGs on climate change is over-emphasised. Carter et al. 2006, for example, in part 1 of the oft-cited ‘dual critique’ of the Review, noted that, in relation to the IPCC’s third assessment report (IPCC 2001c):

... the IPCC still rated the ‘level of scientific understanding’ of nine out of twelve identified climate forcings as ‘low’ or ‘very low’, highlighted the limitations and short history of climate models, and recognised large uncertainties about how clouds react to climate forcing. Since then, major scientific papers have claimed, among other things, that the forcings of methane has been underestimated by almost half, that half the warming over the twentieth century might be explained by solar changes, that cosmic rays could have a large effect on climate, and that the role of aerosols is more important than that of greenhouse gases. (Carter et al. 2006, p. 171)

This leads Carter et al. to conclude that the Review’s:

... apodictic claim that ‘An overwhelming body of scientific evidence indicates that the Earth’s climate is rapidly changing, predominantly as a result of increases in greenhouse gases caused by human activities’ is without foundation. (Carter et al. 2006 p 173)

Subsequent journal articles have challenged these claims (see, for example, Mitchell et al. 2007; Arnell, Warren and Nicholls 2007; and Glikson 2007). These writers have declared that understanding of many of the scientific issues raised in the dual critique has improved since the IPCC’s third assessment report and that it is Carter et al., rather than the Review, that suffer from selection bias in their use of the science.

The merit of scientific arguments that depart from the IPCC’s consensus view is a matter that cannot be resolved for this paper.

## **2.2 Stern and the effects of anthropogenic emissions**

The Review reports that the present stock of atmospheric GHGs is equivalent to around 430 ppm CO<sub>2</sub> equivalent (CO<sub>2</sub>e), compared with 280 ppm before the industrial revolution. It notes that, if annual emissions do not increase beyond the current rate, the stock of GHGs would reach 550 ppm CO<sub>2</sub>e by 2050. However, because annual emissions flows are accelerating, the Review concludes that 550 ppm CO<sub>2</sub>e could be reached by 2035 at which level there is at least a 77 per cent chance, and perhaps up to a 99 per cent chance (depending on the climate model used) of a global average temperature rise exceeding 2°C relative to pre-industrial levels.

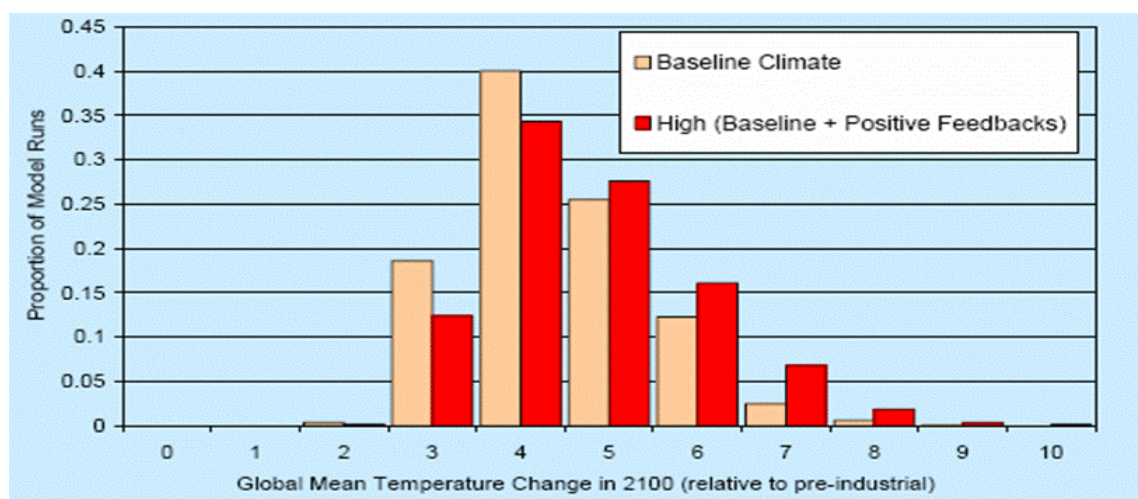
The Review projects that under a business-as-usual scenario, the stock of GHGs could more than treble by the end of the century, giving at least a 50 per cent risk of exceeding 5°C global average temperature change during the following decades. It warns that this

would take humanity into uncharted territory — for example, the Earth is now only around 5°C warmer than in the last ice age.

The Review’s estimates, using the PAGE2002 Integrated Assessment Model, are based only on the IPCC’s A2 emissions scenario which generates the second highest emissions levels of all the six IPCC scenarios (box ). The Review provides estimates for a ‘baseline climate’ and for a ‘high climate’ (figure 2.6). The latter is designed to capture effects if temperature is pushed to higher levels by amplifying feedbacks in the climate system, such as weakened carbon sinks and increases in natural methane releases.

Under the baseline scenario assumptions, there is estimated to be a 90 per cent probability that the temperature will increase between 2.4 and 5.8°C by 2100, relative to pre-industrial. The corresponding confidence interval for the high scenario is 2.6–6.5°C.

**Figure 2.6 The Stern Review’s climate scenarios**



Source: Stern (2007c).

As noted, the Review gives projections of temperature increases to 2100 under various scenarios *relative to the pre-industrial era*. The projections estimated subsequently in IPCC (2007c) (see figure 2.5) are *relative to 1980-1999*. After adjustments are made to equilibrate the IPCC’s and the Review’s projections, the projected temperature changes are generally consistent (table 2.1).

**Table 2.1 Projected global average warming and sea level rise at 2100**  
IPCC 2007 and Stern Review projections

Case	Best estimate (°C)	Likely range(°C)	Sea level rise (metres)
<b>IPCC 2007 projections <sup>a</sup></b>			
— B1 scenario	1.8	1.1–2.9	0.18–0.38
— A1T scenario	2.4	1.4–3.8	0.20–0.45
— B2 scenario	2.4	1.4–3.8	0.28–0.43
— A1B scenario	2.8	1.7–4.4	0.21–0.48
— A2 scenario	3.4	2.0–5.4	0.23–0.51
— A1F1 scenario	4.0	2.4–6.4	0.26–0.59
<b>Adjusted Stern Review projections <sup>b c</sup></b>			
— Baseline climate	3.4	1.9–5.3	ns
— High (baseline + positive feedbacks)	3.8	2.1–6.0	ns

<sup>a</sup> Temperature change and sea level rise at 2090-2099 relative to 1980-1999. Estimates are assessed from a hierarchy of models. Sea level rise projections exclude future rapid dynamical changes in ice flow. <sup>b</sup> The Review's 'raw' estimates are for mean warming in 2100 relative to pre-industrial. These have been adjusted to a similar basis as the IPCC's estimates by subtracting 0.5°C for warming in the period 1850-1899 to 1980-1999 (see IPCC 2007c, footnote 8). This still leaves a minor inconsistency — the IPCC's 2090-2099 end point differs to the Review's end point of 2100. <sup>c</sup> Likely temperature range reflects 90 per cent confidence interval, whereas the IPCC's +/- 1 standard deviation equates to a 68 per cent confidence interval.

Source: IPCC (2007c); Stern (2007c).

That said, chapter 1 of the Review, states:

If annual greenhouse gas emissions remained at the current level, concentrations would be more than treble pre-industrial levels by 2100, committing the world to 3–10°C warming...

... As the world warms, the risk of abrupt and large-scale changes in the climate system will rise....

- If the Greenland or West Antarctic Ice Sheets began to melt irreversibly, the rate of sea level rise could more than double, committing the world to an eventual sea level rise of 5 – 12 m over several centuries. (Stern 2007c, p. 2)

This is consistent with a general tendency of the Review to lead with headline messages that incorporate the 'tail' of lower probability outcomes. Hence, notwithstanding the similarity of the projections outlined in table 2.1, the Review elevates more adverse climate change consequences than does the IPCC.

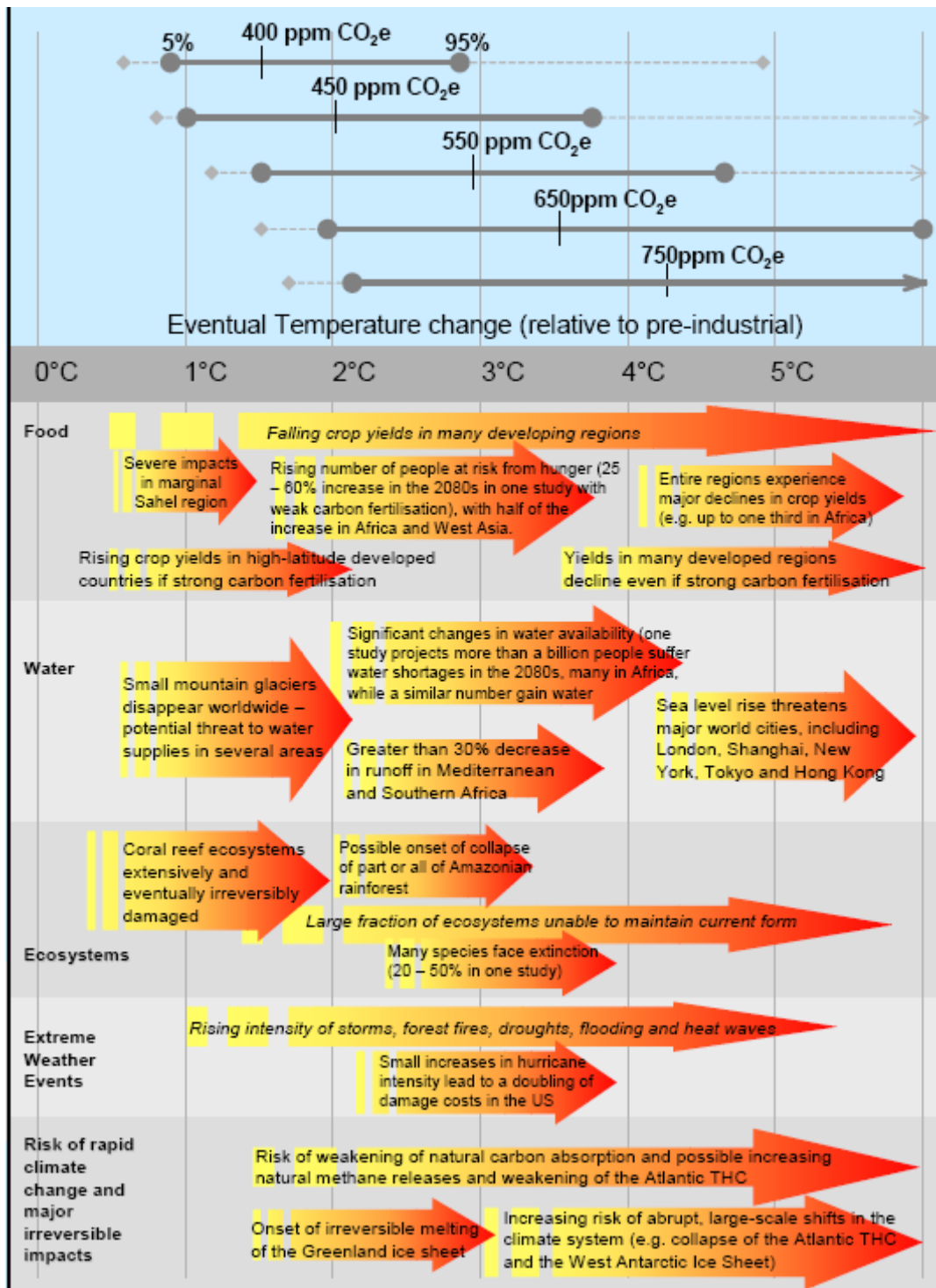
## **Stern Review: projected impacts of climate change**

The Review's projected impacts of higher GHG concentrations are shown in figure 2.7. The top panel shows projected temperature ranges for stabilisation levels between 400 ppm and 750 ppm of CO<sub>2</sub>e. The solid horizontal lines show the 5–95 per cent range based on climate sensitivity estimates (taken from IPCC 2001c, based on Wigley and Raper 2001



and Murphy et al. 2004). The vertical lines indicate the mean of the 50<sup>th</sup> percentile point. The dashed lines show the 5–95 per cent range based on 11 recent studies (Meinshausen 2006).

Figure 2.7 **Stabilisation levels and probability ranges for temperature rises**



Source: Stern (2006b).

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The bottom panel of figure 2.7 indicates that warming is projected to have increasingly severe impacts. The Review postulates:

- rising sea levels could result in hundreds of millions of people being flooded
- serious impacts on global food production with warming above 4°C
- an increase in deaths from malnutrition, heat stress and vector-borne diseases such as malaria
- that around 15-40 per cent of species potentially face extinction (with warming above 2°C).

For purposes of comparison, figure 2.8 summarises the IPCC's assessment of the likelihood that:

- trends towards more extreme events can already be observed
- there is a human contribution to observed trends
- future emissions are likely to contribute to further trend developments.

While the two approaches are generally consistent qualitatively, the Review's projections appear to ascribe more definitive probabilities to outcomes for certain temperature ranges.

Damages and estimates of damage costs are the subject of the next chapter.

## 2.3 Summary

It is universally accepted that the concentration of GHGs in the atmosphere is rising and that human activity is contributing to this rise. It has also been established that there has been measurable mean global warming since the 19<sup>th</sup> century.

There is an emerging consensus that anthropogenic emissions have caused the Earth to warm. What is less well understood is the degree of climate sensitivity to different GHG concentrations and the effects of any temperature response on natural and human systems.

Looking forward, climate models are used to generate probabilities for future states.

The Review's warming projections generally accord with the most recent projections of the IPCC. Nevertheless, the Review has a tendency to 'headline' higher, less certain, estimates of warming and sea level rise.

Figure 2.8 Human contribution to extreme weather events

Phenomenon <sup>a</sup> and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend <sup>b</sup>	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	<i>Very likely<sup>c</sup></i>	<i>Likely<sup>d</sup></i>	<i>Virtually certain<sup>d</sup></i>
Warmer and more frequent hot days and nights over most land areas	<i>Very likely<sup>e</sup></i>	<i>Likely (nights)<sup>d</sup></i>	<i>Virtually certain<sup>d</sup></i>
Warm spells/heat waves. Frequency increases over most land areas	<i>Likely</i>	<i>More likely than not<sup>f</sup></i>	<i>Very likely</i>
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	<i>Likely</i>	<i>More likely than not<sup>f</sup></i>	<i>Very likely</i>
Area affected by droughts increases	<i>Likely in many regions since 1970s</i>	<i>More likely than not</i>	<i>Likely</i>
Intense tropical cyclone activity increases	<i>Likely in some regions since 1970</i>	<i>More likely than not<sup>f</sup></i>	<i>Likely</i>
Increased incidence of extreme high sea level (excludes tsunamis) <sup>g</sup>	<i>Likely</i>	<i>More likely than not<sup>h</sup></i>	<i>Likely<sup>i</sup></i>

Table notes:

- <sup>a</sup> See Table 3.7 for further details regarding definitions.
- <sup>b</sup> See Table TS.4, Box TS.5 and Table 9.4.
- <sup>c</sup> Decreased frequency of cold days and nights (coldest 10%).
- <sup>d</sup> Warming of the most extreme days and nights each year.
- <sup>e</sup> Increased frequency of hot days and nights (hottest 10%).
- <sup>f</sup> Magnitude of anthropogenic contributions not assessed. Attribution for these phenomena based on expert judgement rather than formal attribution studies.
- <sup>g</sup> Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.
- <sup>h</sup> Changes in observed extreme high sea level closely follow the changes in average sea level. {5.5} It is *very likely* that anthropogenic activity contributed to a rise in average sea level. {9.5}
- <sup>i</sup> In all scenarios, the projected global average sea level at 2100 is higher than in the reference period. {10.6} The effect of changes in regional weather systems on sea level extremes has not been assessed.

Source: IPCC (2007c).

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## 3 Damages (and benefits) from climate change

The Review examines the damages (and benefits) of climate change in two ways. First, the various bio-physical impacts of climate change and their effects on human welfare and the environment are identified. Second, an Integrated Assessment Model (IAM) is used to estimate overall damage costs over time.

This approach is a conventional one. However, it is important to appreciate that the two exercises are largely independent. The impact analysis is based on a review of existing literature, complemented by supporting research commissioned for the Review. The modelling is based on relationships between temperature increases and costs given in IPCC (2001a) and estimates of temperature increases from IPCC (2001c) and some more recent studies.

### 3.1 Impact on physical, biological and human systems

The Review discusses the effects of climate change on water availability, food production, health, land and the environment, as well as the effects of extreme weather events and abrupt, large-scale impacts.

The results of this impact analysis are expressed in physical units (for example, the amount of, or percentage change in, water runoff), as a probability of certain events occurring or the number of people likely to be affected. Economic valuation of the damages is necessary if damages are to be expressed in common units. However, no monetary values are reported in this section of the Review. A summary of the impacts discussed in the Review is given in table 3.1.

#### **Water availability**

The Review reports that climate change is expected to influence the distribution of freshwater across regions as well as its seasonal and annual variability due to changes in precipitation (including more droughts or floods) and the loss of glaciers and mountain snow which serve as freshwater reservoirs storing water in the winter

**Table 3.1 Possible impacts of climate change discussed in the Review**

Temp rise (°C)	Water	Food	Health	Land	Environment	Abrupt and Large-Scale Impacts
1°C	Small glaciers in the Andes disappear completely, threatening water supplies for 50 million people	Modest increases in cereal yields in temperate regions	At least 300,000 people each year die from climate-related diseases (predominantly diarrhoea, malaria, and malnutrition)  Reduction in winter mortality in higher latitudes (Northern Europe, USA)	Permafrost thawing damages buildings and roads in parts of Canada and Russia	At least 10% of land species facing extinction (according to one estimate)  80% bleaching of coral reefs, including Great Barrier Reef	Atlantic Thermohaline Circulation starts to weaken
2°C	Potentially 20 - 30% decrease in water availability in some vulnerable regions, e.g. Southern Africa and Mediterranean	Sharp declines in crop yield in tropical regions (5 - 10% in Africa)	40 – 60 million more people exposed to malaria in Africa	Up to 10 million more people affected by coastal flooding each year	15 – 40% of species facing extinction (according to one estimate)  High risk of extinction of Arctic species, including polar bear and caribou	Potential for Greenland ice sheet to begin melting irreversibly, accelerating sea level rise and committing world to an eventual 7 m sea level rise
3°C	In Southern Europe, serious droughts occur once every 10 years  1 - 4 billion more people suffer water shortages, while 1 – 5 billion gain water, which may increase flood risk	150 - 550 additional millions at risk of hunger (if carbon fertilisation weak)  Agricultural yields in higher latitudes likely to peak	1 – 3 million more people die from malnutrition (if carbon fertilisation weak)	1 – 170 million more people affected by coastal flooding each year	20 – 50% of species facing extinction (according to one estimate), including 25 – 60% mammals, 30 – 40% birds and 15 – 70% butterflies in South Africa  Onset of Amazon forest collapse (some models only)	Rising risk of abrupt changes to atmospheric circulations, e.g. the monsoon  Rising risk of collapse of West Antarctic Ice Sheet
4°C	Potentially 30 – 50% decrease in water availability in Southern Africa and Mediterranean	Agricultural yields decline by 15 – 35% in Africa, and entire regions out of production (e.g. parts of Australia)	Up to 80 million more people exposed to malaria in Africa	7 – 300 million more people affected by coastal flooding each year	Loss of around half Arctic tundra  Around half of all the world's nature reserves cannot fulfil objectives	Rising risk of collapse of Atlantic Thermohaline Circulation
5°C	Possible disappearance of large glaciers in Himalayas, affecting one-quarter of China's population and hundreds of millions in India	Continued increase in ocean acidity seriously disrupting marine ecosystems and possibly fish stocks		Sea level rise threatens small islands, low-lying coastal areas (Florida) and major world cities such as New York, London, and Tokyo		
More than 5°C	The latest science suggests that the Earth's average temperature will rise by even more than 5 or 6°C if emissions continue to grow and positive feedbacks amplify the warming effect of greenhouse gases (e.g. release of carbon dioxide from soils or methane from permafrost). This level of global temperature rise would be equivalent to the amount of warming that occurred between the last [ice] age and today – and is likely to lead to major disruption and large-scale movement of population. Such 'socially contingent' effects could be catastrophic, but are currently very hard to capture with current models as temperatures would be so far outside human experience.					

Source: Stern (2007c).

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and releasing it in the summer. Less water storage may increase flood risk during wet seasons and threaten dry-season water supplies.

Broadly, it is expected that differences in water availability between regions will become increasingly pronounced. Areas that are already relatively dry (such as the Mediterranean basin, parts of Southern Africa, South America and Australia) are anticipated to experience further decreases in water availability. In contrast, water availability in South Asia and parts of Northern Europe and Russia could increase. This view is consistent with the finding of the latest IPCC report:

Changes in precipitation show robust large-scale patterns: precipitation generally increases in the tropical precipitation maxima, decreases in the subtropics and increases at high latitudes as a consequence of a general intensification of the global hydrological cycle. (IPCC 2007d, p. 89)

Changes in precipitation and water availability can have diverse effects on human welfare. For instance, while an increase in water runoff may be welcome in some instances, it may also cause flooding, endangering lives, property, infrastructure and water quality.

## **Sea levels**

Global warming is projected to lead to rising sea levels (see chapter 2). This could potentially have impacts on human and biological systems. It would increase the cost of coastal protection, and in the absence of adaptive measures, could increase coastal flooding, lead to loss of wetlands, coastal erosion, increase saltwater intrusion into surface and groundwater and displace people in low-lying coastal areas.

The Review cites one study which estimates that between 7 and 300 million additional people might be flooded each year by a 20–80 cm sea level rise caused by 3 to 4°C of warming. (The projections of the latest Intergovernmental Panel on Climate Change report (IPCC 2007c) anticipate that sea level will rise by 18 to 59 cm by 2100.) Of course, the number of people at risk depends in part on different population scenarios. Upgrading coastal defences could partially offset these impacts, but this would, the Review argues, require substantial capital investment and ongoing maintenance.

The Review emphasises that sea levels could rise much more rapidly and higher if the Greenland and West Antarctic ice sheets began to melt irreversibly. Even if this

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were to happen over a much longer timescale of centuries, a sea level rise in the range of 5 to 12 m would have more drastic consequences.<sup>1</sup>

## **Ecosystems and biodiversity**

Ecosystems are vulnerable to climate change, in particular if it occurs too rapidly for species to adapt. The Review draws on the literature to report that as little as 1°C of warming could lead to the extinction of 10 per cent of land species and cause more frequent coral reef bleaching. At 2°C warming 15 to 40 per cent of land species could be facing extinction. Coral reefs would be expected to experience annual bleaching in many areas. At 3°C above pre-industrial temperatures, between 20 and 50 per cent of land species could be threatened by extinction.

The results are not inconsistent with IPCC (2007a), which reports that approximately 20–30 per cent of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5–2.5°C. For higher increases in global average temperature, the IPCC reports that changes in ecosystem structure and function, species' ecological interactions, and species' geographic ranges are expected, with predominantly negative consequences for biodiversity, and ecosystem goods and services (for example, water supply).

Stern does not discuss the value of ecosystems and biodiversity. The values involved relate to direct and indirect use, as well as to option, existence and bequest values (Dziegielewska et al. 2007).

## **Food production**

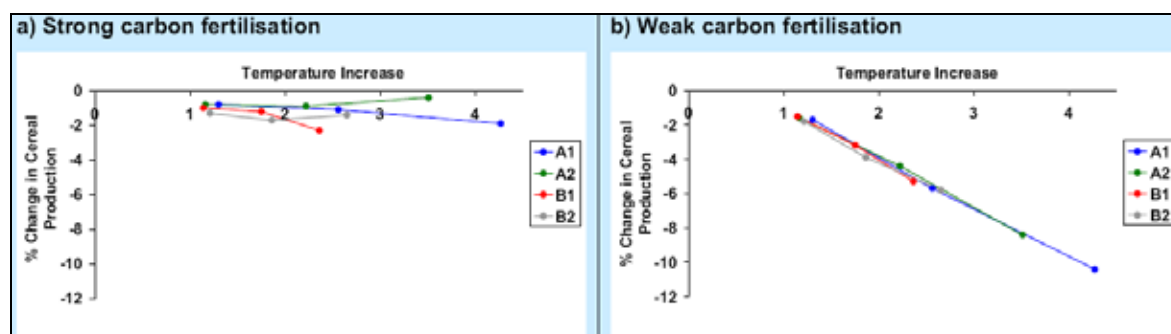
Projected impacts of climate change in specific regions depend on initial conditions (how warm and dry), as well as on the degree of warming and water availability. Another critical factor is the extent to which higher atmospheric concentrations of carbon dioxide have beneficial effects on plant growth (the so-called 'carbon fertilisation' effect). The size of the carbon fertilisation effect is a subject of dispute in the literature. The Review contends that the effect is likely to be no more than half that typically included in crop models.

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<sup>1</sup> According to IPCC(2007c), the volumes of the Greenland and Antarctic Ice Sheets are equivalent to approximately 7 metres and 57 metres of sea level rise, respectively. However, ice core data show that neither ice sheet was completely removed during warm periods of at least the past million years.

The Review presents the expected impact on cereal production (compared to a future world without climate change) with strong and weak carbon fertilisation (figure 3.1). It shows that the expected loss of output would be relatively small with a strong carbon fertilisation effect, but may be more than 10 per cent if the carbon fertilisation effect were small.

**Figure 3.1 The impact of global warming on cereal production**  
Percentage change compared to world without climate change



Source: Stern (2007c).

The Review contends that the effects might be even more negative because previous studies:

- have focused on temperature increases of up to 4°C. At higher temperatures ‘agricultural collapse across large areas of the world is possible ... but clear empirical evidence is still limited’ (Stern 2007c, p. 81).
- usually do not take into account a range of impacts of climate change that are likely to have negative effects on food production (such as, reduction of species (in particular pollinators), floods, and climate-induced pests and diseases).

The Review warns that the impacts on agriculture and fisheries could place many people at risk of malnutrition, particularly in developing countries.

Not all studies share the Review’s pessimistic view. Some assume that a higher carbon fertilisation effect or adaptation could offset the negative impacts.

Hitz and Smith (2004), which the Review cites extensively, survey five studies investigating the possible effects of climate change on agricultural production. Their conclusions are as follows.

- All studies indicate variation across regions — with the disparities in crop production between developed and developing countries expected to increase.
- Results on global agriculture are ambiguous up to 3 to 4°C warming, but impacts are expected to be increasingly adverse beyond this threshold.



- 
- If climate change results in increased climate variance, greater threat of pests, substantial reductions in irrigation supply, or less efficient or effective adaptation, the threshold could be lower.
  - In the long term, the impact of socioeconomic change may be larger than climate change — therefore, the results (in particular for people at risk of hunger) depend strongly on assumptions about socioeconomic change.

## Human health

Climate change may have beneficial as well as adverse impacts on human health. The Review discusses the following projected impacts (which are primarily adverse).

- The number of cold-related deaths would decrease in cold regions (northern latitudes in Europe, Russia, Canada and United States), whereas health impacts and deaths from heat stress are expected to increase.
- Droughts and floods may directly cause death from dehydration and drowning and also might endanger access to clean water leading to an increase of water-borne diseases (for example, diarrhoeal diseases).
- A wider distribution and abundance of disease vectors (in particular mosquitoes) may lead to a spread of vector-borne diseases (for example malaria and dengue fever) if effective control measures are not in place.
- Extreme weather events (for example, storms, droughts and floods) may have direct and indirect health impacts.
- In areas with declining output in agriculture and fisheries more people could suffer from malnutrition and related health impacts.

The Review cites a World Health Organisation estimate that, since the 1970s, climate change is responsible for over 150 000 deaths each year through increasing incidence of diarrhoea, malaria and malnutrition, predominantly in Africa and other developing regions. According to the World Health Organisation an increase in global temperature of 1°C (above pre-industrial levels) could double this number of deaths.

Hitz and Smith (2004) survey the literature on health impacts and conclude that:

- health risks are more likely to increase than decrease as the temperature rises
- while the reduction in cold-related mortality may dominate the increase of heat-related mortality for small temperature increases, higher rises are likely to increase mortality

- 
- there is substantial uncertainty about the impacts.

Critics have argued that the Review's presentation is too negative, primarily because it fails to take into account the possibilities of preventing and mitigating a large share of the impacts as societies grow wealthier. Tol and Dowlatabadi (2001) consider that mortality from malaria can be reduced to virtually zero by providing access to public health services. Thus, economic development over this century would have a stronger impact on health than climate change. Tol et al. (2006) conclude:

Climate change and its impact on malaria are important only if there is hardly any development over the 21<sup>st</sup> century. Other infectious diseases behave similarly to malaria. (p. 7)

They warn that:

... assessments of the impacts of climate change that ignore the nuances in the relationships between the economic development and vulnerability can grossly misrepresent the risks of that change. (p. 2)

## **Extreme weather events**

According to the Review, most impact studies 'have focused predominantly on changes in average conditions and rarely examine the consequences of increased variability and more extreme weather' (Stern 2007c, p. 68). The Review contends that the costs of extreme weather events<sup>2</sup> (for example, storms, floods, droughts and heat waves) could increase substantially as a consequence of climate change 'both by shifting the probability distribution upwards (more heatwaves, but fewer cold-snaps) and by intensifying the water cycle, so that severe floods, droughts and storms occur more often' (Stern 2007c, p. 68).

The Review contends also 'that impacts in many sectors will become disproportionately more severe with rising temperatures' (Stern 2007c, p. 71). It concludes that: 'based on simple extrapolations, costs of extreme weather alone could reach 0.5–1% of world GDP per annum by the middle of the century, and will keep rising if the world continues to warm' (Stern 2006b, p. viii).

However, the Review acknowledges that 'empirical support for these relationships is lacking' (Stern 2007c, p. 71). It refers to the study by Hitz and Smith (2004) that reviewed studies that examined the relationship between the impacts of climate

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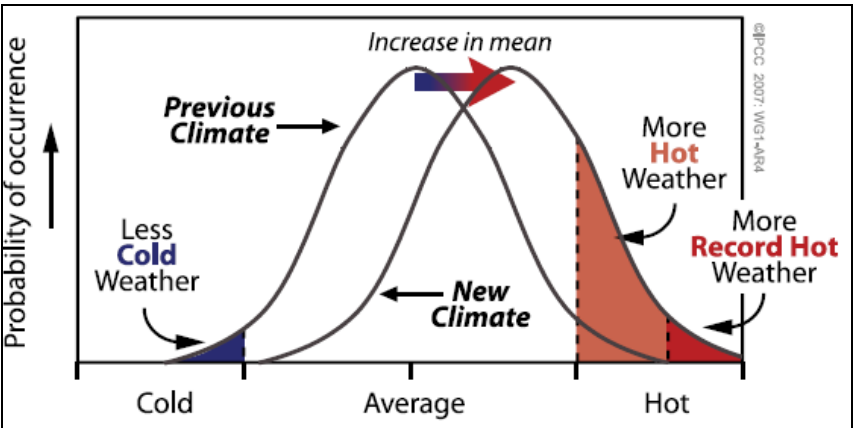
<sup>2</sup> 'Extreme events' are defined as occurrences where 'a climate variable (e.g. temperature or rainfall) exceeds a particular threshold, e.g. two standard deviations from the mean.' (Stern 2007c, p. 68.)

change and increasing global temperatures. Hitz and Smith found increasingly adverse impacts for several climate-sensitive sectors but were not able to determine if the increase was linear or exponential. For sectors like water and energy they found no consistent relationship with temperature.

Scientific evidence of the impact of climate change on extreme events is not conclusive. The latest IPCC report acknowledges that, while linking a particular extreme event to a single, specific cause is problematic, statistical reasoning indicates ‘that substantial changes in the frequency of extreme events ... can result from a relatively small shift of the distribution of a weather or climate variable’ (IPCC 2007d, 53). Figure 3.2 illustrates that an upward shift in the distribution as a whole will disproportionately increase the probability of extreme events and cause new ‘record’ events with previously unobserved extremes.

In conclusion, there is substantial uncertainty about the nexus between global warming and the damages from extreme weather events.

Figure 3.2 Effect of mean temperature increases on extreme temperatures



Source: IPCC (2007d).

**Non-linear changes and threshold effects**

Most research on damage costs focuses on climate change impacts that occur gradually as climate forcing increases. However, the earth’s climate is a complex dynamic system, and in the past various incidences of abrupt large-scale climate changes seem to have taken place (see chapter 2, figure 2.4).

The focus on the risk of triggering such large scale and irreversible climate change is one of the quintessential characteristics of the Review. Thus, Weitzman observes:

Indeed ... one has the feeling that the immorality of relegating future generations to live under the shadow of the open-ended possibilities of uncertain large-scale changes

in the climate system ... is a major underlying leitmotif of the Review. (Weitzmann 2007, p. 22–3)

Most climate scientists estimate that the probability of human emissions triggering such impacts is low, but not negligible. The Review emphasises that ‘the latest science indicates that the risk is more serious than once thought... Some temperature triggers, like 3 or 4°C of warming, could be reached this century if warming occurs quite rapidly’ (Stern 2007c, p. 95). Potential temperature triggers for such phenomena listed in the Review are reproduced in table 3.2.

**Table 3.2 Potential temperature triggers for large-scale and abrupt changes in climate system**

Phenomenon	Global Temperature Rise (above pre-industrial)	Relative Confidence*	References
Shifts in regional weather regimes (e.g. changes in monsoons or the El Niño)	Uncertain (although some changes are expected)	Medium	Hoskins (2003)
Onset of irreversible melting of Greenland	2 - 3°C	Medium	Lowe <i>et al.</i> (2006)
Substantial melting threatening the stability of the West Antarctic Ice Sheet	> 2 - 5°C	Low	Oppenheimer (2005)
Weakening of North Atlantic Thermohaline Circulation	Gradual weakening from present	High	Wood <i>et al.</i> (2006)
Complete collapse of North Atlantic Thermohaline Circulation	> 3 - 5°C	Low	O'Neill and Oppenheimer (2002)

Source: Stern (2007c).

Such changes might be irreversible — at least on human time scales — and the damages that might be inflicted could be very high. The Review warns that this could potentially destabilise regions and increase regional conflict. It warns that a melting/collapse of polar ice sheets would accelerate sea level rise and might increase the sea level by 5 to 12 m over coming centuries. This would eventually lead to substantial loss of land, affecting around 5 per cent of the global population including many major cities (such as New York, London and Tokyo). Also, warming may induce sudden shifts in regional weather patterns, such as the Asian and African monsoons or the El Niño–Southern Oscillation, with severe consequences for water availability and food production.

## Summary and discussion

The Review — like most of the relevant literature — emphasises the lack of data, non-comparability of impact studies and the pervasive uncertainties. However, its presentation of selected research and the conclusions drawn do not reflect more

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optimistic views found in the literature. This has led to reproaches that its treatment was biased. While it is true that the Review's presentation does not give equal weight to more optimistic views, the results of the impact analysis are generally consistent with the latest IPCC report.

The Review also seems largely compatible with, although somewhat less circumspect than, a review of the global impacts literature by Hitz and Smith (2004). The findings of Hitz and Smith include the following.

- At lower levels of climate change, the relationships range from increasing adverse impacts (in coastal resources, biodiversity, health, and possibly marine ecosystem productivity), to relationships where beneficial impacts are experienced at low to moderate levels of climate change (agriculture, terrestrial ecosystem productivity), to no consistent pattern (water, energy, aggregate costs).
- None of the available studies suggested positive impacts from climate change in any sector as temperatures increased beyond certain levels (3-4 °C). It appears likely that as temperatures exceed this range, impacts in the vast majority of sectors will become increasingly adverse.

Another criticism levelled at the Review's analysis of damages of climate change is that it does not appropriately take into account the possibility of adaptation measures. Ideally there should be a more systematic analysis of different combinations of adaptation and associated damages. The Review acknowledges that adaptation could reduce damage costs substantially (figure 3.3). Most of the impact analysis presented by the Review assumes adaptation at the level of individuals or firms, but not economywide adaptations due to policy intervention.<sup>3</sup> Systematic studies of the trade-off between adaptation and damage costs on a global level are not available and further research is required in this area.

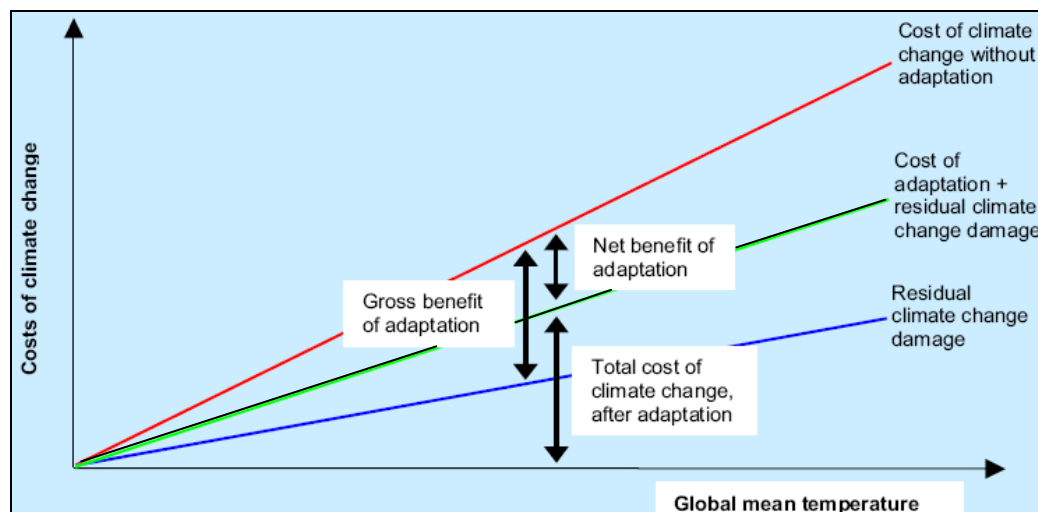
Another important criticism concerns the relationship between economic and social development and the damages from climate change. Some authors contend that vulnerability to some of the negative impacts of climate change (such as a spread of vector or water-borne diseases, famine and access to clean water) is confined mainly to developing countries, because they lack the capacity to deal with them effectively. Failing to recognise this, it is argued, can lead to overestimates of damages, because developing countries can be expected to become much wealthier and resilient before climate change could have major impacts. Also, assistance for adaptation and/or general economic development might be an efficient way to contain damages. While this aspect is not examined in the Review's impact

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<sup>3</sup> In the modelling of overall damage costs different assumptions are made, namely that 90 per cent of the impacts are adapted to in rich countries, and 50 per cent in poor (see section 3.2).

analysis, sensitivity analysis has been conducted for aggregate damage costs (see chapter 5).

Figure 3.3 The role of adaptation in reducing climate change damages



Source: Stern (2007c).

## 3.2 Modelling of the costs of climate change

### The Review's approach

The Review uses an Integrated Assessment Model (IAM), PAGE2002, to estimate damage costs for the cost-benefit analysis. IAMs simulate the key human and natural processes believed to be driving climate change and estimate the socioeconomic impacts. The Review opted to use PAGE2002 largely because it is able to simulate costs across a wide range of possible impacts and attach probabilities to the range of resulting damage cost estimates.

### Scenarios

Using PAGE2002, damage costs were estimated out to 2200, for two different climate change scenarios (baseline and high climate) and three different sets of impact categories (figure 3.4).

The baseline climate change scenario is based on the Intergovernmental Panel on Climate Change's 'A2' scenario.<sup>4</sup> The high climate scenario assumes a higher

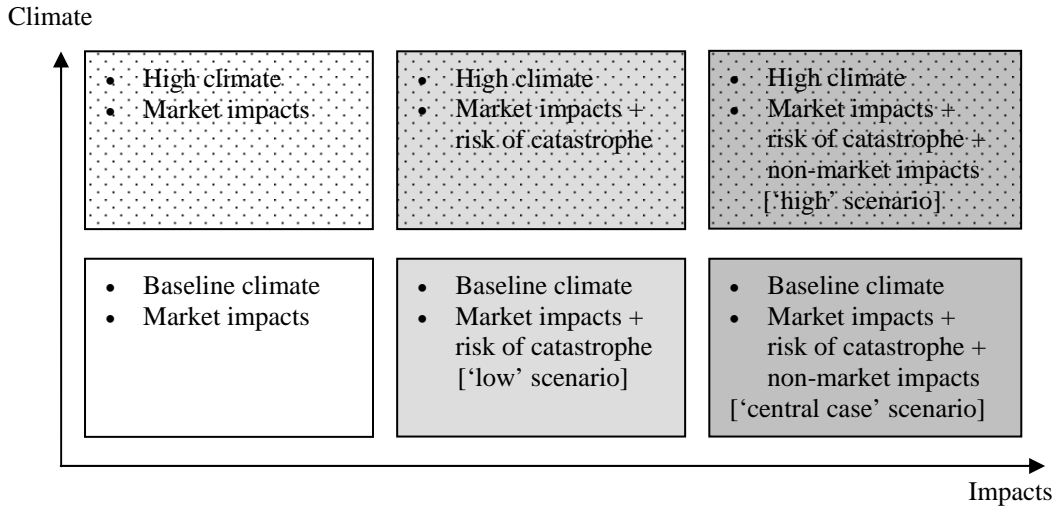
<sup>4</sup> The 'A2' scenario is one of six IPCC emission marker scenarios (chapter 2).

climate sensitivity than the baseline scenario, on the basis of recent evidence suggesting that amplifying feedbacks could be important.

Temperature changes are useful to illustrate the two scenarios. Under the baseline scenario assumptions, there is a 90 per cent probability that the temperature increase will be between 2.4 and 5.8°C in 2100, relative to the pre-industrial era. The corresponding confidence interval for the high scenario is 2.6–6.5°C. While the difference between the two scenarios seems small, the probability of greater than 6°C of warming — an outcome that is likely to be associated with major damages from climate change — is about 3 per cent under the baseline scenario, compared with almost 10 per cent under the high scenario (figure 2.6).

The Review defines three impact categories — market impacts, non-market impacts and the risk of catastrophic events — and the scenarios differ as to which they include (figure 3.4). Market impacts include only the effects of climate change that impact on market sectors of the economy. Non-market impacts are direct effects of climate change on human health and the environment for which no market price exists. Catastrophic events are losses from abrupt or discontinuous changes that could occur at higher levels of warming (see section 3.1).

**Figure 3.4 Matrix of climate scenarios and impact categories**



Source: Stern (2007c).

*Treatment of uncertainty*

The PAGE2002 model deals with the uncertainty inherent in the range of possible impacts using a ‘Monte Carlo’ simulation. Each scenario is run 1000 times. For each run, parameters are chosen at random from the ranges given in the climate change literature, so that the PAGE2002 model summarises the range of underlying

research studies. The Monte Carlo simulation yields a probability distribution of damage cost estimates. This probability distribution can be used to give a point estimate that accounts for uncertainty, attitudes to risk and time preferences (see chapter 5).

### *Calibration of the damage cost curve*

In PAGE2002, damage costs are calculated as GDP losses that are an ‘uncertain power function of temperature rise’ (Warren et al. 2006, p. 30). Costs are calculated for each of the eight world regions distinguished by the model. Total damage is added up from market and non-market costs as well as damages from abrupt climate change.

The damage function is calibrated with a benchmark estimate of impacts from the literature for a mean temperature rise of 2.5°C over pre-industrial levels. The benchmark values — taken from IPCC (2001a) — are given in table 3.3.

**Table 3.3 Impact parameters in PAGE 2002, version 1.4**

<i>PAGE2002 Impact Parameter</i>	<i>Mean</i>	<i>Min</i>	<i>Mode</i>	<i>Max</i>	<i>Metric (where relevant)</i>
Impact function exponent	1.77	1	1.3	3	
Market impact	0.50	-0.1	0.6	1	%GDP loss for 2.5°C
Non-market impact	0.73	0	0.7	1.5	%GDP loss for 2.5°C
Loss if catastrophe occurs	11.67	5	10	20	%GDP

Source: Warren et al. (2006).

The sensitivity of damages to temperature increase is an uncertain variable. Its most likely value (mode) of 1.3 (table 3.3) goes back to Cline (1992), the range is taken from Peck and Teisberg (1992).

The sum of market and non-market impacts is modelled to be consistent with the IPCC’s Third Assessment Report (IPCC 2001a, table 19.4).

The damages from abrupt climate change (catastrophe) have been estimated to be an order of magnitude greater than the impacts from continuous change, which is reported as being ‘broadly consistent’ with the IPCC’s Third Assessment Report (Warren et al. 2006, p. 31). The chance of a catastrophic event is estimated to be zero at temperatures below 5°C above pre-industrial levels. Beyond this the risks increase by 1 to 20 per cent (most likely 10 per cent) for each subsequent 1°C rise in temperature. The probability of a catastrophic event is based on the approach used by Nordhaus and Boyer (2000), which involved polling a number of experts.



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PAGE2002 has the capability to allow for adaptation to climate change. Impacts are modelled to occur above some time-dependant profile of tolerable region-specific and sector-specific temperature rise. In the absence of adaptation the tolerable temperature rise is assumed to be zero (except for damages from abrupt climate change where a higher threshold is defined as described above). Adaptation can be modelled to influence the tolerable level or rate of temperature rise as well as the damages from an increase above the tolerable level. PAGE assumes that 90 per cent of the impacts are adapted to in rich countries, and 50 per cent in poor (Stern 2007b).

### *Simulation results*

While six scenarios were modelled, the Review essentially dismisses the two that include only market impacts. The rationale for this is that ‘the omission of the very real risk of abrupt and large-scale changes at high temperatures creates an unrealistic negative bias in estimates’ (Stern 2007c, p. 177). Accordingly, the ‘low’ estimate of damage costs given in the Review is based on the ‘baseline climate with market impacts and risk of catastrophe’ scenario. As shown in figure 3.5a, the mean estimate of damage costs for this scenario rises to 5.3 per cent of global GDP in 2200. This estimate carries much uncertainty, with a 10 per cent probability that damage costs are either less than 1 per cent or over 12 per cent of GDP.

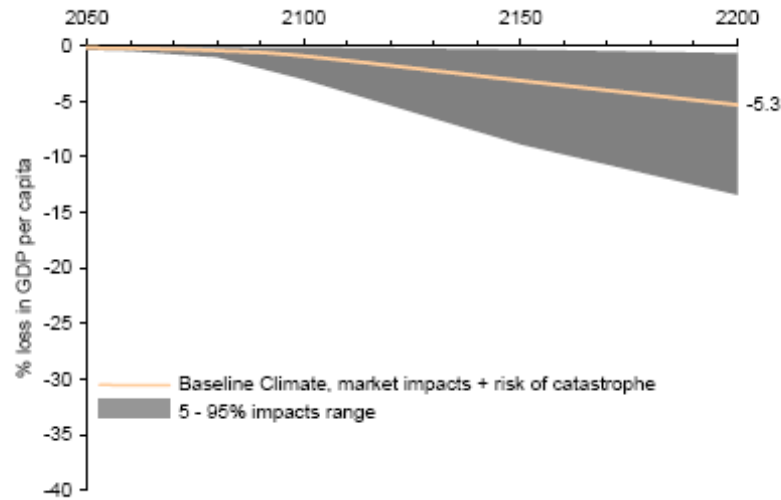
Adding non-market impacts and changing to the high climate scenario yields a ‘high’ estimate of damage costs with a mean of 13.8 per cent of GDP in 2200 (figure 3.5b). There is an even larger range of uncertainty in the high estimate of damage costs than in the low estimate.

Non-market impacts are the most important difference between the low and high estimates — adding non-market impacts to the low estimate scenario gives a mean estimate of damage costs of 11.3 per cent of GDP by 2200. This scenario is described in the Review as the ‘central case’.

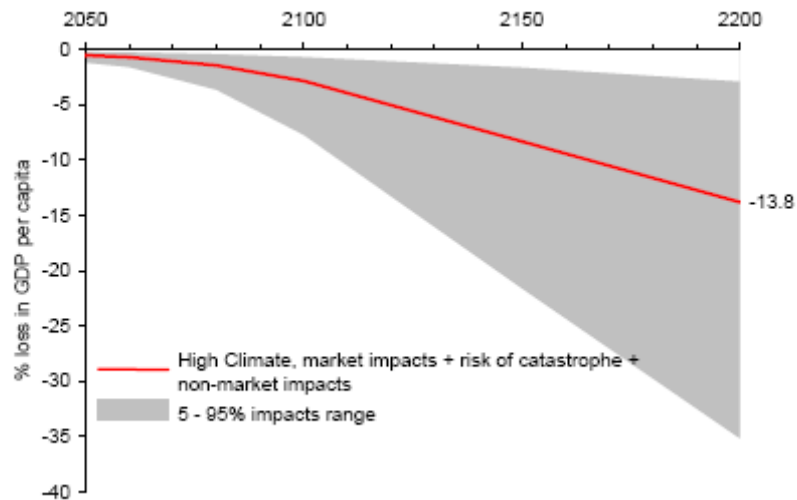
The Review assumes that the ‘world instantaneously overcomes the problems of climate change in the year 2200’ (Stern 2007c, p. 184). This does not mean, however, that there are no costs associated with climate change after this date. Rather, it is assumed that GDP grows at the same rate (1.3 per cent) for all model runs from 2200 onwards. This means that GDP continues to be lower than it would have been without the preceding 200 years of climate change.

Figure 3.5 **Damage costs**

(a) low estimate



(b) high estimate



Source: Stern (2007c).

## Discussion

The Review's estimation of damage costs displays some significant differences to existing studies using similar approaches: Most existing studies:

- consider increases in average temperatures, but not increased variability and more extreme weather events

- 
- do not take into account the potential impacts of large-scale climate shifts<sup>5</sup>
  - monetise only those impacts that are related to market-based activities, such as agricultural production or consumption of energy, or damages to assets that have a market value, excluding damages to human health, biodiversity and ecosystems
  - analyse temperature rises up to 4 or 5°C, not higher increases.

The Review notes that estimates of the non-market impacts and the risk of abrupt, large-scale climate change are more uncertain than the economic costs. Their inclusion has been criticised in several instances. Byatt et al. (2006, p. 203) denounce the inclusion of ‘very speculative non-economic costs with little empirical guidance’ as a ‘methodological departure’.

However, other mainstream models, such as DICE/RICE and MERGE, include non-market costs.<sup>6</sup> Non-market costs are a standard element of environmental cost–benefit analysis and uncertainty does not justify their exclusion. Low-probability impacts with the potential of very high damages are also relevant to decision-making on climate policy. The Review presents the results for the three impact categories separately, allowing decision makers to take into account the respective uncertainties.

The Review’s modelling approach adds one novel feature — the explicit treatment of uncertainty. PAGE2002 allows for ‘Monte Carlo’ simulations, where uncertain parameters are chosen at random from the ranges given in the climate change literature and thus enable a probability distribution over the possible outcomes.

In the Review, the damage cost paths discussed above (figure 3.5) are aggregated over time and translated into ‘balanced growth equivalents’. This aggregation is based on several crucial assumptions about discount rates and the treatment of risk. These issues concern the aggregation of damages and of mitigation costs. They are discussed in chapter 5 of this paper, together with sensitivity analyses and a comparison with results from other models.

### 3.3 Summary

The Review presents two approaches to analysing the impacts of climate change.

- An impact analysis discusses the effects of climate change on water availability, sea levels, ecosystems, food production and human health (in physical units).

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<sup>5</sup> A notable exception is Nordhaus and Boyer (2000).

<sup>6</sup> Warren et al. (2006) give an overview of the treatment of damage costs by various models.

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- Overall damage estimates are derived using an Integrated Assessment Model.

Estimates of the impacts of climate change in the literature vary widely. Some impacts may be beneficial for some regions at low levels of warming, but are expected to be increasingly negative with higher temperature increases. The Review emphasises the potential negative impacts, but acknowledges the controversies and uncertainties of impact assessments.

The results drawn from the impact analysis are at the upper end of the range of the literature, because the Review draws heavily on some recent scientific literature that has a more pessimistic view on climate change and its impacts, and gives little regard to parts of the literature with a more optimistic view.

The modelling results have a more extensive coverage of damage costs than most previous studies, including market and non-market impacts as well as the risk of abrupt, large-scale climate change.

The Review provides limited focus on the potential for adaptation measures to reduce damages and for social and economic development to reduce vulnerability to climate change.

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## 4 Mitigation costs

The costs of responding to climate change are just as important for policy decisions as the damage costs. Policymakers need to consider the costs as well as the benefits from action. For its part, the Review's key conclusion relies on estimates of the costs of action — its call for strong early action on climate change is based, in part, on its comparison of damage costs equivalent to 5 to 20 per cent of GDP and mitigation costs of 1 per cent of GDP.<sup>1</sup>

This estimate of mitigation costs relates to the total annual costs in 2050 associated with a stabilisation target of 500–550 ppm carbon dioxide equivalent (CO<sub>2</sub>e). The stabilisation target adopted for the Review is influenced by analysis that shows that mitigation costs increase steeply for more stringent targets (box 4.1, see also chapter 6). The cost estimate for 2050 is used to give an indication of the time path for costs over the coming century. There is less confidence in mitigation cost estimates for the second half of the century, but 'the average expected cost is likely to remain around 1%' (Stern 2006b, p. xiv). The focus on total costs is justified by a discussion of why total costs are more relevant than marginal abatement costs (box 4.2).

**Box 4.1 Mitigation costs increase rapidly as mitigation efforts become more ambitious**

Total cost increases rapidly as mitigation efforts become more ambitious, because as more mitigation is undertaken, more costly options must be pursued. Further, more stringent targets will require significant reductions in emissions over the next couple of decades, which could necessitate retiring emissions-intensive capital assets early (such as coal-fired power stations).

Based on macroeconomic modelling results, Stern finds that increases in the amount of mitigation are likely to necessitate a 'greater-than-proportionate increase in costs' (Stern 2007c, p. 269). For example, the cost of stabilising emissions at 450–500 ppm CO<sub>2</sub>e is estimated to be around three times the cost of stabilisation at 500–550 ppm CO<sub>2</sub>e.

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<sup>1</sup> The terms 'mitigation' and 'abatement' are generally used interchangeably in the climate change literature. They both refer to reducing greenhouse gas emissions.

#### Box 4.2 Total, marginal and average abatement costs

Stern contends that total abatement costs are more important than marginal costs when deciding whether large-scale mitigation is worthwhile, because changes are large and ‘the marginal abatement cost ... is an appropriate measuring device only in the case of small changes’ (Stern 2007c, p. 241). However, Stern also compares marginal abatement costs with marginal damage costs to determine whether immediate action is merited at the margin. The conclusion is that action is merited on this basis because abatement costs are negative in some cases, whereas damage costs are positive.

Total abatement costs are closely linked to average abatement costs, because the latter is obtained by dividing total abatement costs by the quantity of abatement.

The distinction between marginal and average abatement costs is important, because they are likely to follow different paths over time. Stern points out that ‘[t]he marginal abatement cost should rise over time to remain equal to the social cost of carbon, which itself rises with the stock of greenhouse gases in the atmosphere’ (2007, p. 241). Average costs will be less than marginal costs (as the most expensive projects are undertaken last) and will depend both on the depth of emission cuts and the pace at which technological change brings down total costs of abatement. Thus, it is possible for average costs to fall (or at least rise more slowly) even as marginal abatement costs increase (Stern 2007c, box 9.6). This is the case for the resource cost estimates presented by Stern, which show average costs decreasing over time (table below), while marginal costs rise (Dietz et al. 2007).

Table **Average mitigation costs decreasing over time**  
Resource cost estimates in the Stern Review (fossil fuel abatement only)

		2015	2025	2050
Average cost of abatement	US\$/tCO <sub>2</sub>	61	33	22
Emissions abated (relative to BAU)	GtCO <sub>2</sub>	2.2	10.7	42.6
Total cost of abatement	US\$ billion	134	349	930

Source: Stern (2007c).

In the climate change literature, two basic approaches are used to estimate mitigation costs: resource costs (or bottom-up) and macroeconomic modelling (or top-down) (IPCC 2001b). In either case, mitigation costs are dependent on a host of different factors, which makes it difficult to estimate costs precisely (box 4.3). The conclusions in the Review draw on estimates using both resource cost and macroeconomic modelling approaches.

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#### Box 4.3 Key factors influencing mitigation costs

Several factors have been identified as key determinants of mitigation costs.

- *Depth of emission cuts*: costs increase rapidly with deeper emission cuts. The amount of mitigation required is given by the ‘mitigation gap’ between the emissions goal and business-as-usual emissions (Stern 2007c). Business-as-usual emissions depend on population and productivity growth rates, developments in the relative price of fossil fuels, technological change, and the availability of less carbon-intensive sources of energy (IPCC 2001b).
  - *Technological change*: the rate and characteristics of technological change play an important part in determining mitigation costs. According to IPCC (2001b), important characteristics of technological change concern the existence and extent of:
    - a ‘backstop’ technology<sup>2</sup> — the existence of a carbon-free backstop technology would reduce mitigation costs (Edenhofer et al. 2006)
    - induced technological change — mitigation costs are lower if policy changes induce technological change (Edenhofer et al. 2006)
    - potential emissions savings from increased energy efficiency — some estimates suggest that efficiency in the use of fossil fuels is likely to be the single largest source of fossil fuel-related emission savings in 2050 (IEA 2006a). In some cases, efficiency improvements are seen as ‘negative cost’ abatement opportunities.
  - *Price elasticities*: estimates of price-induced substitution possibilities between fuels and between energy and other inputs can be crucial for mitigation costs (IPCC 2001b). The extent to which price increases in emissions-intensive goods lead to less consumption of these goods will also be important.
  - *Efficiency of policy*: Mitigation costs are lower when there is ‘what’, ‘where’ and ‘when’ flexibility over how emission savings are achieved (Stern 2007c).
    - ‘What’ flexibility refers to having a wide choice of sectors and technologies and the inclusion of non-CO<sub>2</sub> emissions.
    - ‘Where’ flexibility implies that emission-saving efforts are concentrated in parts of the globe where mitigation costs are lowest.
    - ‘When’ flexibility relates to the timing of mitigation.
- Whether revenues from policy measures are ‘recycled’ to reduce distorting taxes or to provide incentives for low-carbon innovation is also an important determinant of mitigation costs (Edenhofer et al. 2006).
- *Extent of ‘ancillary benefits’*: ancillary benefits are effects of climate change mitigation on problems other than greenhouse gas emissions, such as reductions in local air pollution (IPCC 2001b). Ancillary benefits are potentially important in reducing the net cost of mitigation (Stern 2007c).<sup>3</sup>

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<sup>2</sup> A backstop technology refers to a fuel that becomes perfectly elastic in supply at a given price.

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## 4.1 Resource cost approach

The resource cost approach uses costs of individual emission-saving measures to estimate mitigation costs — a ‘bottom-up’ approach. Emission-saving measures can include improving energy efficiency, substituting toward low-emissions technologies, planting new forests and avoiding deforestation. As the resource cost approach does not use an economywide model, ‘second round’ effects (such as feedbacks between the energy sector and the rest of the economy) are generally not included, nor are opportunities to respond that involve price-induced reductions in demand for high-emissions goods and services.

### Estimate of mitigation costs in the Stern Review

Using the resource cost method, the Review concludes that a 550 ppm CO<sub>2</sub>e target will cost about 1 per cent of GDP by 2050.

This estimate was reached by considering the costs of a portfolio of fossil fuel and non-fossil-fuel related measures. For fossil fuel emissions, Stern envisages savings coming from a portfolio of technologies (figure 4.1). Fossil fuel technologies constitute almost four-fifths of the total abatement by 2050. The remaining one-fifth of abatement comes from cutting non-fossil-fuel related emissions. Measures include reforestation, avoiding deforestation, changes to land management practises, and reducing non-CO<sub>2</sub> emissions from energy-related sources and agriculture. On average, non-fossil-fuel emission reduction is estimated to be about half as expensive (per tonne of CO<sub>2</sub>) as fossil fuel reductions.

The resource cost estimate carries a large degree of uncertainty. In the main body of the report, the Review is clear on this uncertainty: ‘even in the near to medium term, the uncertainties are very large’ (Stern 2007c, p. 253). As well as the central estimate of 1 per cent of GDP, a range from -1 per cent to 3.5 per cent is given. This range is based on the sensitivity of the estimates to assumptions about technological change and the depth of emission cuts required.

The Review presents the resource cost estimate of 1 per cent of GDP as an upper bound estimate of costs and justifies this on the grounds that ‘it does not take account of opportunities to respond involving reductions in demand for high-carbon goods and services’ (Stern 2006b, p. xiii). Stern also notes that ‘there generally will

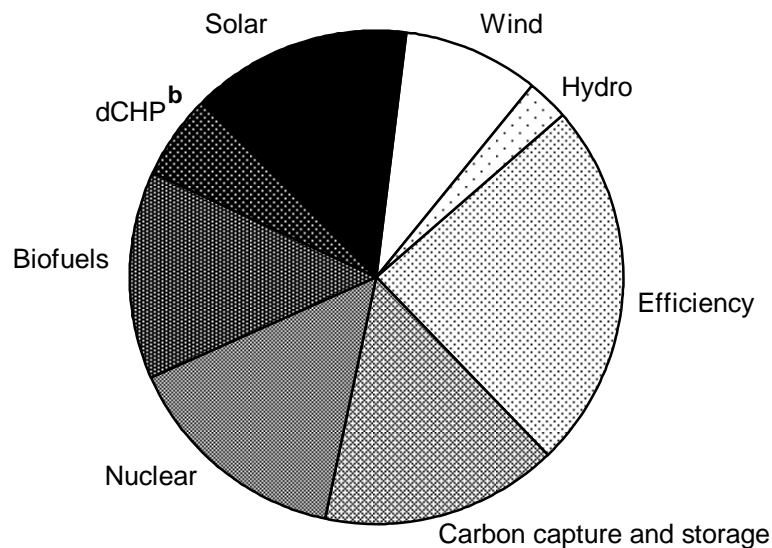
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<sup>3</sup> If one were to carry out a traditional cost–benefit analysis and weigh the ‘costs’ of climate change mitigation on one hand against its ‘benefits’, then ancillary benefits would be included on the ‘benefits’ side of the ledger along with avoided damages from climate change. However, because damages from climate change are generally estimated separately from ancillary effects, studies that consider ancillary benefits tend to do so as an offset to mitigation costs.



be cheaper methods than any one particular set [of ways of reducing emissions] chosen by assumption' (Stern 2007c, p. 241). Further, the resource cost method does not include ancillary benefits in the cost estimate.

Figure 4.1 **Sources of emission savings, 2050**  
Fossil fuel emissions only — total abatement of 43 GtCO<sub>2</sub><sup>a</sup>



<sup>a</sup> Non-fossil-fuel emission savings of 11 GtCO<sub>2</sub> were also included in the resource cost estimates.

<sup>b</sup> Decentralized forms of generation and combined heat and power.

Source: Stern (2007c).

## Discussion

While the points noted by Stern are valid, the resource cost estimate is not necessarily an upper bound on costs. There are other effects, such as feedbacks between the energy sector and the rest of the economy, that the resource cost estimates ignore and which could lead to higher costs. In its third assessment report, the Intergovernmental Panel on Climate Change (IPCC) reported that '[i]n previous studies, bottom-up models tended to generate relatively low mitigation costs' (IPCC 2001b, p. 489). In the summary for policymakers of their subsequent assessment report, the IPCC found that at an aggregate level 'top-down studies are in line with bottom-up studies' (IPCC 2007b, p. 11), with no suggestion that bottom-up studies represented an upper bound on costs. The resource cost estimates are also unlikely to represent an upper bound on costs if assumptions about factors such as the rate of technical change and the efficiency of policy instruments turn out to be optimistic.

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Besides the optimism of framing costs as an ‘upper bound’ estimate, there have been some other criticisms of the Review’s resource cost estimates. While critiques of the review have tended not to dwell on the resource cost estimates to any great extent, Tol and Yohe (2006) and Mendelsohn (2006) both criticise Stern’s approach. Tol and Yohe (2006) contend that Stern underestimates costs because of the omission of impacts on economic growth and capital stock turnover. However, Anderson (2007) counters that capital stock turnover *was* allowed for in the resource cost estimates. Mendelsohn (2006) expresses a view that allowing for carbon capture and storage is overly optimistic because it is not yet a proven technology, and that the amount of land required for renewable energy on the scale proposed would have secondary effects that are not considered by Stern.

To give an indication of how the Review fits in with other studies, its estimates can be compared with previous estimates in the literature. Two of the most widely quoted sources of resource cost estimates are the IPCC and the International Energy Agency (IEA). Estimates from these sources are independent of those in the Review and are useful for comparison purposes.

#### *Intergovernmental Panel on Climate Change (IPCC) estimates*

A summary of results from bottom-up studies is presented in the summary for policymakers of the contribution of working group III to the IPCC’s fourth assessment report (IPCC 2007b). These results incorporate both fossil fuel and non-fossil-fuel mitigation.

The IPCC’s estimates are broadly consistent with those in the Review. Direct comparison of the Review’s cost estimate of 1 per cent of GDP by 2050 is not possible because the IPCC only reports bottom-up estimates until 2030, and focuses on marginal costs of mitigation. The IPCC suggests that mitigation consistent with meeting the Review’s target can be achieved at a marginal cost of US\$50 per tonne of CO<sub>2</sub> in 2030.<sup>4</sup> Marginal costs will be higher than average costs (box 4.2), so the IPCC estimate of marginal costs of US\$50 per tonne of CO<sub>2</sub> in 2030 does not conflict with the Review’s average cost (for fossil fuel mitigation only) of around US\$30 per tonne of CO<sub>2</sub> in that year (Stern 2007c, figure 9.5). In fact, using Anderson’s (2007) figure of marginal costs of 2-4 times average costs, the IPCC estimates for 2030 appear to be slightly more optimistic than those in Stern, based on the marginal costs alone.

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<sup>4</sup> The IPCC reports that mitigation of 13 to 26 GtCO<sub>2</sub> is likely to be available in 2030 at a marginal cost of US\$50 per tonne of CO<sub>2</sub>. This is consistent with the emissions scenarios underlying the resource cost estimates in the Stern Review, which project just over 15 GtCO<sub>2</sub> abatement from fossil fuel related sources in 2030 (Stern 2007c, figure 9.3) and further abatement from non-fossil-fuel related abatement.

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### *International Energy Agency (IEA) estimates*

The IEA released two reports in 2006 containing estimates of the costs of reducing fossil fuel emissions using a resource cost approach: *World Energy Outlook* (IEA 2006b) and *Energy Technology Perspectives* (IEA 2006a). Both reports conclude that significant cuts in emissions are possible from a range of different technologies, at little or no net cost.

The IEA estimates are of particular interest because they were summarised within the Review. Section 9.9 of the Review uses the two IEA reports to support its resource cost estimates.

The alternative policy scenario in IEA (2006b) analyses how the global energy market could evolve if countries were to adopt all of the policies they are currently considering related to energy security and energy-related CO<sub>2</sub> emissions. Under the alternative policy scenario, fossil-fuel CO<sub>2</sub> emissions are cut by 6.3 gigatonnes (Gt) relative to the reference scenario in 2030. As the IEA explains, these emission reductions carry no net cost:

... energy and emissions savings in the Alternative Policy Scenario can be achieved at net benefit (negative cost) to society. This is not to say the savings are free, but rather that the higher capital spending to improve energy efficiency is more than offset by savings in consumers' fuel expenditures over the lifetime of the equipment'. (IEA 2006b, p. 205)

In IEA (2006a), five accelerated technology scenarios are used to demonstrate that technologies that already exist, or are likely to become commercially available in the next two decades, can be used to return global energy-related CO<sub>2</sub> emissions toward today's level by 2050. The main alternative policy scenario is estimated to reduce fossil fuel related emissions in 2050 by 32 GtCO<sub>2</sub>e at a net discounted cost of US\$100 billion, incurred over the period 2005-2050. Under the discount rate used by the IEA for this exercise (5 per cent) this is equivalent to net costs of less than US\$6 billion per year, or less than 0.02 per cent of world GDP in 2005.<sup>5</sup> However, these estimates exclude the costs of research and development that would be needed to sustain the accelerated technology scenarios.

In finding that there are significant emissions savings available at little or no cost, the IEA estimates mirror the optimism in Enqvist, Naucler and Rosander (2007)<sup>6</sup> (figure 4.2). This is likely to be overly optimistic because, as the IPCC (2001b) has said, 'the key question is ... the extent to which market imperfections that inhibit

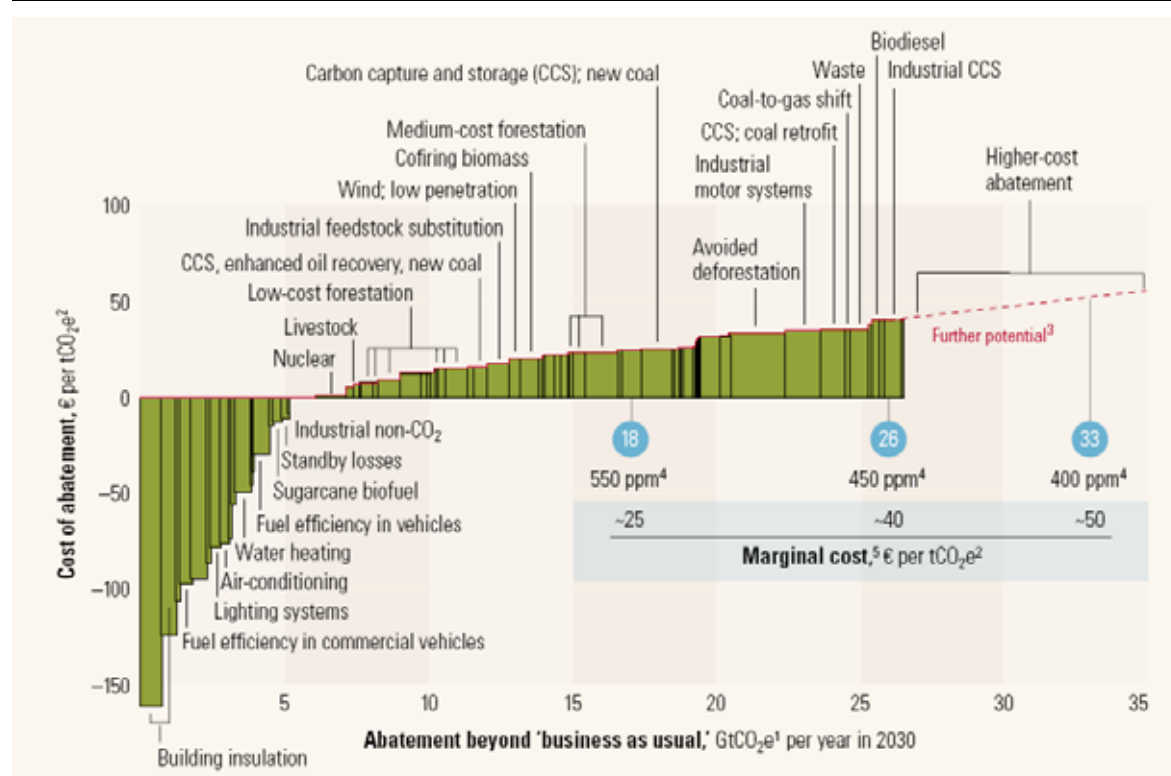
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<sup>5</sup> World GDP in 2005 was approximately US\$45 trillion (World Bank 2007).

<sup>6</sup> In addition to similarities between the conclusions of the two studies, Enqvist, Naucler and Rosander (2007) use the IEA's business-as-usual projections.

access to these potentials can be removed cost-effectively by policy initiatives’ (p. 503). To put it another way, if abatement yields benefits irrespective of the climatic impacts, then why isn’t this abatement being done already? And how will policy change this? In the Australian context, the Productivity Commission concluded that ‘the scope for achieving environmental gains through increasing the uptake of only those energy efficiency improvements that are privately cost effective appears to be modest’ (PC 2005, p. xx).

Figure 4.2 **Cost of abatement technologies**  
Estimates from Enqvist, Naucler and Rosander (2007)



Source: Enqvist, Naucler and Rosander (2007).

In *World Energy Outlook* and *Energy Technology Perspectives*, the IEA finds that reductions in fossil fuel emissions are significantly less costly than suggested by the Review. This can be partly explained by differences in the mitigation targets. The *World Energy Outlook* estimates relate to significantly less mitigation than in the Stern Review (6.3 GtCO<sub>2</sub> compared with about 16 GtCO<sub>2</sub> from fossil fuel emissions abatement in 2030 in the Review<sup>7</sup>). *Energy Technology Perspectives* also considers the costs of less abatement (32 GtCO<sub>2</sub> compared with 43 GtCO<sub>2</sub> in the Review) and excludes costs associated with additional research and development.

<sup>7</sup> Stern (2007c), figure 9.3.

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Differences between the Review's resource cost estimates and those from the IEA are also partly explained by differences in how much mitigation is assumed to be available from energy efficiency measures at negative or little cost. The Review assumes that less emissions savings are available through efficiency than does the IEA (2006b) (Anderson 2006). Given the difficulties with accessing gains from privately cost effective energy efficiency measures noted in PC (2005), Stern's more moderate estimates are probably preferred to those of the IEA. However, the Review does cite the IEA estimates in chapter 9 and, while these are only used as supporting evidence for the Review's own estimates, the use of the IEA estimates should be seen to be optimistic.

Overall, the Review's estimate of mitigation costs of about 1 per cent of GDP by 2050 seems reasonable compared with other resource cost estimates. There is no indication that the estimate in the Review is an outlier, though nor is it clear that it represents an upper bound on costs, as suggested by Stern.

## **4.2 Macroeconomic modelling approach**

Macroeconomic modelling of mitigation explores the economywide effects of the transition to a lower emissions economy. As such, macroeconomic modelling is often referred to as a 'top-down' approach (IPCC 2001b). Macroeconomic modelling uses estimated parameters to model demand and supply. This means that the dynamic interactions of different factors over time can be tracked, including responses to price changes. Some critics complain, however, that macroeconomic models do not contain the sectoral details needed to model mitigation costs accurately (IPCC 2001b).

### **Estimate of mitigation costs in the Review**

Based on macroeconomic modelling, chapter 10 of the Review concludes that 'the expected annual cost of achieving emissions reductions, consistent with an emissions trajectory leading to stabilisation at around 500–550 ppm CO<sub>2</sub>e, is likely to be around 1% of GDP by 2050, with a range of +/-3%' (Stern 2007c, p. 267). The Review says that costs are likely to remain around 1 per cent of GDP from mid-century, but with the range of uncertainty growing over time.

The macroeconomic modelling estimates in the Review are based on meta-analyses of results from a range of models. Stern draws on a broad range of model comparison studies, including those discussed in the following section, and does not cite a particular source for the Review's estimates. However, the focus is mainly on the estimates from a meta-analysis undertaken for the Review (Barker et al. 2006).

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The Barker et al. meta-analysis is based primarily on models that assume climate change policy will stimulate technological change in a way that reduces future mitigation costs. That is, the rates of development of low-emissions technologies will be increased through direct government support for research and development and the incentives created by emissions pricing. Concentrating on models that incorporate this ‘induced technological change’ restricted the analysis to 11 models that estimate costs up to 2050.<sup>8</sup> Nine of the 11 models are part of the Innovation Modelling Comparison Project (IMCP), which is discussed in the following section. Problems identifying the factors affecting the costs of mitigation in such a small dataset meant that the analysis in Barker et al. was extended to include two earlier meta-analyses (Repetto and Austin 1997, and Barker et al. 2002). The results published in the Review (figure 10.1) incorporate all three datasets. The two additional datasets do not generally allow for induced technological change.

## Discussion

Some insight as to how the Stern Review estimates compare with the broader literature are available from comparing the Review’s estimates with those from model comparison projects. Model comparison projects are an ideal benchmark because their estimates are averaged across a range of underlying models, eliminating much of the variability across different models. In this section, model comparison projects are used to highlight the importance of the Review’s treatment of technological change and the divergence between the Review and the literature regarding post-2050 mitigation costs.

The Review’s approach of using macroeconomic modelling to estimate mitigation costs is well supported by the literature. Macroeconomic modelling is the only way to estimate the costs of mitigation over long time periods so as to take account of interactions between the energy sector and the broader economy. Importantly, there are many independent, peer-reviewed estimates of mitigation costs from macroeconomic models (Fischer and Morgenstern 2005).

While the overall approach is valid, how representative are the results? The results of macroeconomic modelling depend crucially on the type of model used and the assumptions made, particularly assumptions concerning the key factors affecting mitigation costs (box 4.3). As a consequence, the results from individual models vary widely — cost estimates presented in the Review alone range from -4 per cent of GDP (net gains) to 15 per cent of GDP.

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<sup>8</sup> One model, ‘PANTA\_RHEI’ only estimates costs up to 2020.

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The Review lists several model comparison projects as some of the most up-to-date and extensive. The literature, as well as the estimates cited in critiques of the Review (for example, in Tol and Yohe 2006), suggest that the Review's list is a reasonable one. Model comparison projects cited by the Review include:

- Stanford University's Energy Modelling Forum (EMF-21)
- the IPCC's Third Assessment Report (TAR)<sup>9</sup>
- the IMCP
- the US Climate Change Science Program's (CCSP) synthesis and assessment of scenarios of greenhouse-gas emissions and atmospheric concentrations.<sup>10</sup>

Compared with estimates from these model comparison projects, the mitigation cost estimates in the Review appear to be optimistic. Mitigation costs in 2050 for stabilisation at 500–550 ppm CO<sub>2</sub>e are at the lower end of the estimates in the literature. Further, the conclusion that costs remain constant as a proportion of GDP from mid-century is not supported by the literature.

Estimated costs in 2050 are relatively low in the Review largely because of its reliance on models (in Barker et al. 2006) that assume climate change policy will induce technological change. Model comparison exercises using models that do not consider induced technological change (EMF-21, IPCC TAR and US CCSP) generally find that mitigation costs for stabilisation at 500–550 ppm CO<sub>2</sub>e will exceed 1 per cent of GDP by 2050 (figure 4.3). The IMCP suggests costs more in keeping with the Stern estimates, because the models in the IMCP incorporate induced technological change. When induced technological change is switched off, average costs from the IMCP are greater than those from the other model comparison projects.

Results from the IPCC's fourth assessment report (IPCC 2007b) further support the importance of induced technological change. IPCC (2007b) considered some models that incorporated induced technological change and reported cost estimates that are close to those in the Review, though for a slightly less stringent target. The report presents a median macroeconomic cost estimate of 1.3 per cent of global GDP in 2050, for stabilisation at 535–590 ppm CO<sub>2</sub>e (just above the stabilisation range considered by Stern).

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<sup>9</sup> The IPCC's fourth assessment report was released after the Stern Review.

<sup>10</sup> The Review also mentions two other comparisons: the meta-analysis study by Fischer and Morgenstern and the International Energy Agency accelerated technology scenarios. Fischer and Morgenstern (2006) is largely based on a study by the EMF to measure the costs of the Kyoto Protocol (EMF-16) and is not as relevant here as more recent EMF work. The International Energy Agency accelerated technology scenarios in IEA (2006a) are based on only one macroeconomic model — the IEA Energy Technology Perspectives model.

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In principle, modelling of mitigation costs should allow for the possibility of induced technological change. The effect of climate change policies on the development and spread of new technologies is an important part of their impact, and among the most important determinants of a policy's success (IPCC 2001b). However, there are practical difficulties. Induced technological change is difficult to model and Barker et al. (2006, p. 1) concede that 'induced technological change is a relatively new topic in economic modelling and results are often experimental and controversial'. Tol claims that because the Review's cost estimates 'are largely inspired by the Innovation Modeling Comparison Project', it incorporates 'overly optimistic assumptions on technological progress and the costs of emission abatement' (Tol 2006, p. 3).

The Review has been criticised for being too optimistic in assumptions about revenue recycling and ancillary benefits from mitigation (Byatt et al. 2006). However, to the extent that revenue recycling and ancillary benefits can be modelled accurately, their inclusion should improve the cost estimates by broadening the analysis to include more of the consequences of climate change mitigation. Further, revenue recycling and ancillary benefits feature in only a few of the models used by Stern, so their effect on the overall conclusions is small.

Revenue recycling and ancillary benefits are two of several factors where, as in other meta-analyses, there are a range of assumptions underlying the Stern estimates. This is common in model comparison projects because different modelling teams incorporate different assumptions on factors relevant to mitigation costs. For example, the models used for the Review incorporate a range of assumptions about backstop technologies and price elasticities. In effect, this means that the results are averages over different assumptions for the key factors driving mitigation costs (outlined in box 4.3).

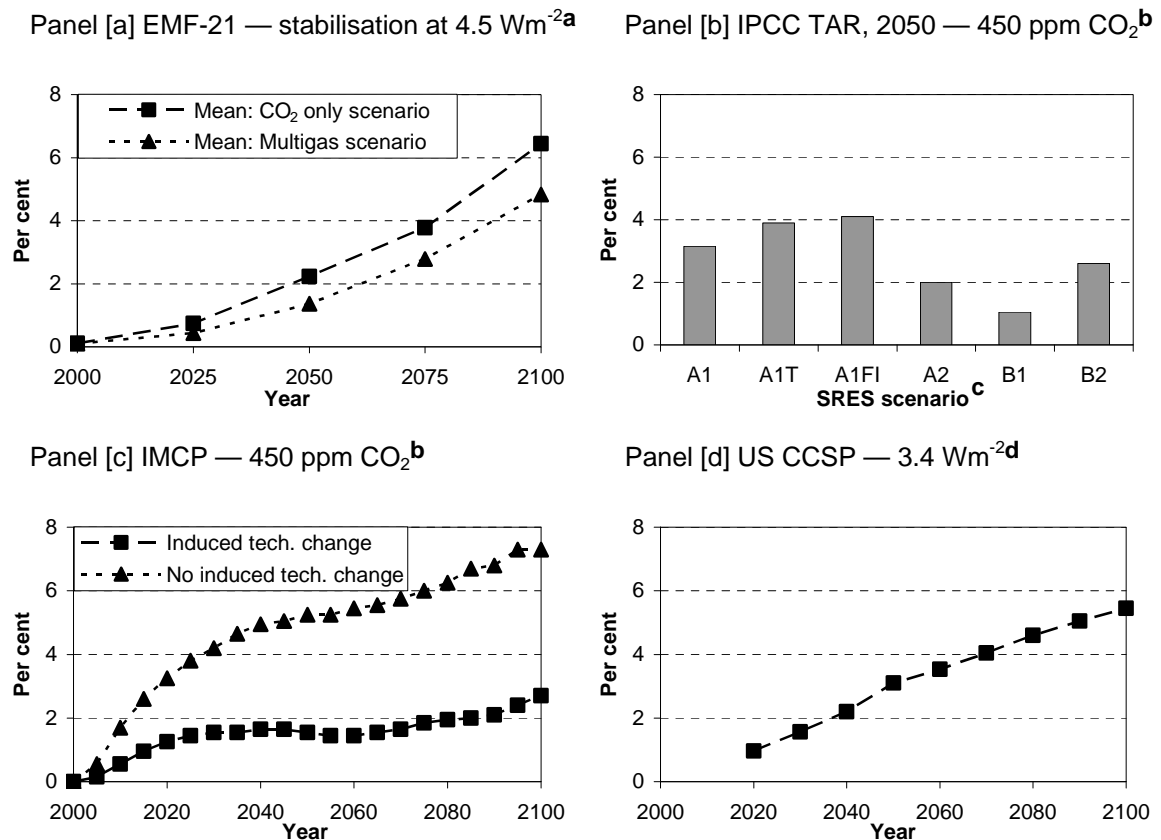
Assumptions on policy are optimistic in some regards and pessimistic in others. The models underlying the Stern estimates are optimistic about 'where' flexibility as the economic instrument is usually emissions trading or taxes at a global level (Barker et al. 2006). However, there is assumed to be little 'what' flexibility in the abatement mix of different greenhouse gases, because the modelling only considers mitigation of CO<sub>2</sub>. The importance of 'what' flexibility is illustrated by the results of EMF-21, which suggest that confining mitigation to CO<sub>2</sub> emissions is likely to increase costs in 2050 by 50 per cent compared with multigas mitigation (figure 4.3).

The basis for the conclusion in the Review that mitigation costs remain constant as a proportion of GDP after 2050 is unclear, as it is not supported by the major model



comparison projects mentioned in the Review. The IMCP<sup>11</sup>, EMF-21 and the US CCSP all suggest that mitigation costs for stabilisation are likely to rise in the second half of the twenty-first century (figure 4.3). The IPCC (2001b and 2007) is not clear on whether mitigation costs are likely to increase or decrease after 2050.

**Figure 4.3 Mitigation cost estimates from model comparison projects**  
Reduction in GDP for stabilisation at, or just above, the Stern target



<sup>a</sup> Radiative forcing of 4.5 Wm<sup>-2</sup> corresponds to a CO<sub>2</sub> concentration of just under 550 ppm (US CCSP 2006; table 1.2) and a CO<sub>2</sub>e concentration of over 550 ppm (Kemfert, Truong and Buckner 2005). Results are averaged over all models that report changes in GDP for the relevant year. <sup>b</sup> 450 ppm CO<sub>2</sub> corresponds with approximately 500–550 ppm CO<sub>2</sub>e, which is the Review's target (Stern 2007c). <sup>c</sup> Emissions marker scenarios from the IPCC's Special Report on Emission Scenarios (IPCC 2000). <sup>d</sup> Chosen so that the associated CO<sub>2</sub> concentration would be roughly 450 ppm, which corresponds with the Review's target (US CCSP 2006).

Sources: Weyant, de la Chesnaye and Blanford (2006); IPCC (2001b); Barker et al. (2006); US CCSP (2006).

<sup>11</sup> Three of the models in the IMCP are of a predominantly exploratory nature (Edenhofer, Lessmann and Grubb 2006). These models could conceivably be responsible for the upward trend in average cost estimates for the second half of the century. However, the majority of the 'central models' identified in the IMCP synthesis report (Edenhofer et al 2006) suggest that costs will rise after 2050 (Rao, Keppo and Riahi 2006; Popp 2006; Bosetti, Carraro and Galeotti 2006).

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## 4.3 Summary and conclusions

Assessing the likely costs of responding to climate change is difficult, because estimates of mitigation costs depend on several key factors, including:

- the depth of emission cuts
- the rate and nature of technological change
- price elasticities
- the efficiency of policy
- the extent of ‘ancillary benefits’ from mitigation.

The Review estimates the annual costs of stabilisation at atmospheric concentrations of 500–550 ppm CO<sub>2</sub>e to be around 1 per cent of global GDP in 2050, and likely to remain around this level after 2050. Overall, these estimates appear to be somewhat optimistic.

The Review is creditable in using both of the two major approaches to estimating mitigation costs — the resource cost approach and the macroeconomic modelling approach.

The resource cost estimates in the Review are broadly consistent with, or if anything slightly less optimistic than, those from other widely quoted sources. However, it is difficult to compare the estimates because of differences in the objectives of the different studies. Some other estimates, especially those by the IEA, are very optimistic about the prospects of achieving substantial mitigation at negative or little cost. Thus, it is not clear that they provide a reliable benchmark for comparison. Also, the Review’s framing of the resource cost estimates as an upper bound on costs is not justified.

Compared with estimates from the major model comparison projects, the macroeconomic modelling estimates in the Review appear to be optimistic. Mitigation costs in 2050 for stabilisation at 500–550 ppm CO<sub>2</sub>e are at the lower end of the estimates in the literature, largely because of a reliance on models that assume technological change will be induced by policy action. Further, the conclusion that costs remain constant as a proportion of GDP from mid-century is not supported by the literature, which generally suggests they will rise.

In any case, the cost estimates depend on certain requirements of policy being met. The Stern estimates reflect ‘the likely costs under a flexible, global policy, employing a variety of economic instruments in cost-effective ways’ (Dietz et al. 2007, p. 151). To the extent that climate change policy departs from these requirements, costs would be expected to increase.

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The cost estimates carry a large degree of uncertainty and this is acknowledged in the body of the report, but not in the headline conclusions. One way that uncertainty could have been incorporated into the Review's conclusions would have been to express mitigation costs in terms of a 'certainty equivalent' that accounted for risk aversion, as was done for damage costs. The Review has been criticised for not doing so (Yohe, Tol and Murphy 2007; Maddison 2007) but Stern has countered that this would make little difference, because the distribution of mitigation cost estimates is far narrower than that of damage costs (Dietz et al. 2007). Regardless, not carrying any acknowledgement of uncertainty in mitigation costs to the headline conclusions could be misleading.

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# 5 Aggregating costs and benefits

Chapters 3 and 4 considered climate change damage costs and mitigation costs as they might occur over time. This chapter examines the aggregation of these costs to give single figure estimates. Aggregation involves discounting over time, dealing with the uncertainty of estimates and deciding whether to weight costs in poorer countries more heavily for equity reasons.

## 5.1 Discounting over time

Because damage costs from climate change are expected to remain relatively small for decades and then increase gradually, the choice of discount rates is critical. The Review uses discount rates that are very low by conventional standards and this has received great attention from critics.

### The Review's approach

Within the welfare economics approach adopted by the Review, an increment of future consumption is typically held to be worth less (that is, have less utility) than an increment of current consumption for two reasons. The Review states:

First, if consumption grows, people are better off in the future than they are now and an extra unit of consumption is generally taken to be worth less, the richer people are. Second, it is sometimes suggested that people prefer to have good things earlier rather than later – ‘pure time preference’ – based presumably in some part on an assessment of the chances of being alive to enjoy consumption later and in some part ‘impatience’. (Stern 2007c, p. 35)

Therefore, to make a unit of future consumption equivalent to a unit of current consumption a discount rate must be applied. In welfare economics, the formula commonly used for this purpose is:

$$\text{Rate of discount} = \delta + \eta g$$

Where:  $\delta$  (‘delta’) is the rate of pure time preference (also called the utility discount rate);  $\eta$  (‘eta’) is the elasticity of the marginal utility of consumption; and  $g$  is the growth rate of per capita consumption.

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For Stern, the fact that climate change will have impacts over a very long time period, and will therefore affect future generations, needs to be considered when choosing  $\delta$ . The Review concludes, on ethical grounds, that the welfare of future generations should be treated on a par with our own and, therefore, that the future should not be discounted simply because it is the future. In support of this position he quotes various economists including Ramsey, Pigou, Solow and Sen. This suggests setting  $\delta$  at zero. Stern, however, settles on 0.1, so as to allow for the possibility of the human race becoming extinct (and therefore, future generations being absent).

Stern takes  $\eta$  to be 1, ‘in line with recent empirical estimates’ (Stern 2007c, p. 184).<sup>1</sup> This implies that people derive the same utility from an additional one per cent of consumption, irrespective of their pre-existing level of consumption. Another implication is that an extra unit of consumption to ‘Person A, with three times the consumption of Person B, would have one third the value to that if the extra unit went to Person B’ (Stern 2007c, p. 662).

Substituting these values for  $\delta$  and  $\eta$  into the equation above results in a discount rate equal to 0.1 plus the growth rate of per capita consumption. In the analysis conducted for the Review, discount rates vary across scenarios and paths (and over time) depending on the growth rate of per capita consumption. This is consistent with Stern’s view that the impacts of climate change could be large relative to the global economy and that using a single set of discount rates for such non-marginal changes is inappropriate.

While it is important to appreciate that Stern uses discount rates that vary, there has been an understandable desire among commentators to have a single rate that can be taken as indicative of discounting in the Review. The Review states that the annual average projection for per capita consumption growth is 1.3 per cent for the period 2001 to 2200 ‘in PAGE2002’s baseline world without climate change’ (Stern 2007c, p. 184). This has led a number of commentators to suggest that the Review uses discount rates of around 1.4 per cent per annum (real) (Mendelsohn 2006; Weitzman 2007). Byatt et al. (2006), however, claim that HM Treasury has supplied data that imply that Stern has used discount rates of 2.1 per cent for the current century, 1.9 per cent for next century and 1.4 per cent thereafter. It is not entirely clear which figures are more indicative of the varying discount rates used in the Review, but a discount rate of 1.4 per cent per annum seems more likely as it is consistent with the Review’s baseline projections for consumption growth.

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<sup>1</sup> Stern also suggests that other values (including higher values) for  $\eta$  could be investigated. No other values were used in the initial analysis, but a postscript to the Review (discussed later) includes sensitivity analysis with  $\eta$  set to 1, 1.25 and 1.5.

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## Discussion

There is a long-standing debate on how to choose appropriate discount rates for public policy evaluation, particularly where long time frames are involved — as they are with climate change. The importance of the discount rate is illustrated in table 5.1.

**Table 5.1 Present value of a future benefit of \$1000, by discount rate**

Time into the future	Discount rates (per annum)				
	1%	2%	4%	6%	8%
100 years	\$369.71	\$138.03	\$19.80	\$2.95	\$0.45
200 years	\$136.69	\$19.05	\$0.39	\$0.01	<\$0.01

Much of the debate focuses on whether a descriptive approach (that begins with evidence from decisions people make) or a prescriptive approach (that begins with ethical considerations) should be taken. There is also debate about whether to use a rate that reflects the returns available from alternative investments (the opportunity cost of capital) or one based on preferences for consumption over time (the rate of time preference). Appendix A examines the arguments for and against these different approaches.

Stern takes a *prescriptive* approach to deriving discount rates, based on ethically determined preferences regarding *consumption* over time. The approach is similar to the one taken by Cline in his book *The Economics of Global Warming* (Cline 1992). Cline used a discount rate of 1.5 per cent per annum. Not surprisingly, with a discount rate similar to Stern's, Cline also advocated strong action to reduce greenhouse gas (GHG) emissions. In 1994, Nordhaus published *Managing the Global Commons*, in which he strongly criticised Cline's approach, arguing that discount rates must be based on market interest rates (that is, be descriptive rather than prescriptive). Nordhaus (1994, p. 132) concluded 'from both empirical and theoretical points of view, Cline's argument for the extraordinarily low discount rate is unsupported and unrealistic'. For his own modelling, Nordhaus settled on a discount rate of 6 per cent initially, declining slowly over time due to an assumption that economic growth slows.<sup>2</sup>

More recently, Nordhaus has modified the discount rates he uses for modelling the economics of climate change, so that they decline somewhat more steeply over time. This decline, however, has only a modest effect because the discount rates are high enough in the initial decades to cause all far-future costs and benefits to be discounted to a low proportion of their original value. Ackerman and Finlayson (2006, p. 6) report that in Nordhaus' analysis 'future costs and benefits are marked down by ... 97% after 100 years. The "hyperbolic" pattern of discount rates after [that] only affects how fast the remaining

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<sup>2</sup> Nordhaus' parameter values initially are  $\delta = 3$  per cent,  $\eta = 1.0$  and  $g = 3$  per cent. This compares to Stern's  $\delta = 0.1$  per cent,  $\eta = 1.0$  and  $g = 1.3$  per cent.

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3% of value vanishes'. Accordingly, even with this revision the differences between Nordhaus and Stern (and also Cline) on discounting are still very large.

Since its release there have been many critiques of the Review's approach to discounting. While some have supported the Review, many of the critiques contend that the discount rates used are too low, either because they are below market rates or because they imply that current generations should be prepared to make unreasonably large sacrifices for future generations that, even with climate change, are expected to be richer. Some of the views expressed are summarised in box 5.1.

It is to be expected that the debate on what discount rates to use to analyse climate change will continue. It is not possible to say that Stern (or for that matter, Nordhaus) is definitively right or wrong in their selection of discount rates. Based on the discussion in appendix A, however, it is possible to draw some conclusions.

- The Review's approach to discounting is based on particular ethical judgements about intergenerational equity that are not designed to be representative of wider opinion and that are different from the judgements of some other climate change analysts. Accordingly, it would have been preferable to present a range of results for different discount rates. Stern did this belatedly in a postscript to the Review, although the highest parameter values included equate to discount rates that are still below those advocated by some (see table 5.2).
- Under the Review's approach, community wellbeing is claimed to be increased by forgoing current consumption in order to make climate-related investments that produce benefits in the long term. Whether these investments are superior to alternative investments is left unanswered by the analysis. This is one of the main criticisms that can be made of prescriptive approaches to discounting in general.

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### Box 5.1 Views on the Review's discounting

**Dasgupta** supports the Review's use of a very low  $\delta$ . He, however, regards  $\eta = 1$  as ethically unattractive as it suggests that 'the distribution of wellbeing among people doesn't matter much' (Dasgupta 2006, p. 7). More particularly, he claims it implies that the current generation should be prepared to make unreasonably large sacrifices even if future generations are expected to be much better off. He suggests that Stern has chosen discounting parameter values to yield desired answers.

**Nordhaus** reiterates that a descriptive approach based on market interest rates should be taken. He also conducts a thought experiment that he says shows that the Review's discounting parameters can lead to 'absurd' and 'bizarre' results, requiring very large sacrifices from the current generation (Nordhaus 2006b).

**De Long** regards the Review's discount rates as probably too low, but he is not sure on this. He points out that Stern estimates that each \$1 invested today to reduce the impact of global warming will improve the state of things in 2200 by \$36. The proposition that current generations are morally obliged to make such investments (as put by Stern) is debateable, but is not 'absurd' or 'bizarre' (as suggested by Nordhaus) (De Long 2006).

**Quiggin** argues that Stern's choice of  $\eta$  is standard and choice of  $\delta$  is consistent with the utilitarian view that all people count equally. He says the existence of contradictions, such as the equity premium puzzle, mean that any combination of discounting parameter values can be used to derive results that are contrary to most people's judgement. Therefore, that some critics have been able to do this for the Review's parameter values is not persuasive, as any proposition can be derived from a contradiction (Quiggin 2006).

**Yohe, Tol & Murphy** argue that it was incumbent on the authors of the Review to present the results of a sensitivity analysis spanning a range of possible utility discount rates in their primary publication (Yohe, Tol and Murphy 2007).

**Weitzman** states that the Review 'predetermines the outcome in favour of strong immediate action' on climate change by selecting discounting parameter values that are a theoretically argued lower bound rather than an empirically-plausible estimate of representative tastes (Weitzman 2007, p. 27). However, he argues that discount rates that are much lower than those conventionally used (but higher than Stern's) are warranted, given uncertainty about which interest rate to use (appendix A). Because Weitzman believes that uncertainty and not ethical considerations warrant lower than normal discount rates, he says that Stern may be proved right for the wrong reasons.

**Beckerman and Hepburn** agree with the Review that market interest rates do not provide a satisfactory guide to choosing discount rates for analysing climate change. However, they see no reason why these rates should be based on the ethical judgements of the authors of the Review. They advocate a more representative approach and suggest that this is likely to lead to higher discount rates (Beckerman and Hepburn 2007).



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- Taking a descriptive approach to discounting, as Nordhaus does, tends to guard against the adoption of sub-optimal investments. It leaves open, however, whether higher yielding investments that could benefit future generations are actually made. Because of this it is argued that projects that could have enhanced social welfare may be rejected.
  - Work by Weitzman (2007), and Newell and Pizer (2001) focuses on uncertainties related to the equity premium puzzle and to market interest rates in the long-term future. They argue that such uncertainty can warrant the use of discount rates that are lower than those usually associated with a descriptive approach to discounting (but still higher than those used in the Review).
  - Some analysts start with the presumption that discount rates used for estimating the costs of climate change must be low, because very long term environmental effects are important and so must not be trivialised through strong discounting (Cline 1992). Environmental considerations are best addressed by appropriately valuing environmental goods and services over time and not by altering the discount rate (Arrow et al. 1996).

## 5.2 Treatment of risk and uncertainty

As discussed in previous chapters, risk and uncertainty pervade the science and economics of climate change. Treatment of risk and uncertainty is, therefore, a major issue.

### The Review's approach

As stated by Stern, 'a major feature of the Review is that the economics of risk is placed at the heart of the economics of climate change' (Stern 2007a). Risk and uncertainty are incorporated in at least four ways, as follows.

1. Six damage cost scenarios, incorporating different assumptions about climate sensitivity and impact categories, are modelled.
2. The cost of uncertain climate catastrophe is estimated and included for some scenarios.
3. Many model runs are done for each scenario and the results are averaged across all runs.
4. A defined degree of risk aversion is applied in aggregating the damage costs for each model run for each scenario.

This section concentrates on the last two of these, while chapter 3 deals with the first two.

The Review argues that if the central estimate for warming is used to estimate damage costs, as has been done in some modelling exercises, this will tend to produce lower

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estimates than if the full range of possible outcomes is considered. This is the case even if a neutral attitude to risk is taken. The reason for this is that damage costs are generally believed not to be symmetrical as you move above and below the central estimate for warming. For example, say that 3°C is the central estimate and 0°C and 6°C the upper and lower bounds. The damage costs for 6°C of warming are generally estimated to be higher than those for 3°C by a margin that is greater than the difference between the damage costs for 3°C and 0°C of warming. The Review takes this asymmetry into account by doing one thousand model runs for each scenario and averaging the damage costs across all runs.

In addition, Stern builds in a defined degree of risk aversion. Under the expected utility approach used by Stern, model runs that have higher damage costs than average receive greater weighting in aggregation than those that have lower than average damage costs. This reflects Stern's view 'that society will be willing to pay a premium (insurance) to avoid a simple actuarially fair gamble where potential losses and gains are large' (Stern 2007c, p. 38). The degree of risk aversion is set by  $\eta$ , the elasticity of the marginal utility of consumption — the same parameter used in discounting over time. As discussed above, Stern's gives  $\eta$  a value of 1.

The influence of these aspects of the Review's treatment of risk on the damage cost estimates is illustrated by Yohe (2006). The Review projects that climate change will reduce average global welfare by an amount equivalent to a permanent cut in per-capita consumption of at least 5 per cent. Yohe implies that this figure would reduce to around 4 per cent if damage costs were symmetrical and a risk neutral approach were taken.

## Discussion

Attempting to take the full range of possible climate outcomes into account in estimating damage costs, as the Review does, is preferable to estimating costs for one possible outcome, as was done in some previous studies. Further, building in a degree of risk aversion appears to be appropriate, given the large stakes at play. Stern essentially treats climate change like an insurance problem under which society is prepared to pay a premium to avoid potentially large losses. This way of viewing climate change is consistent with the approach taken in IC (1991).

Stern tends to stress the importance of the Review's approach to risk in explaining why its damage cost estimates are higher than those in many other studies. While it is true that treatment of risk is a factor, it is a minor one compared to the choice of discount rates. This can be seen most clearly by comparing the Review's findings with those of Nordhaus, as is done later in this chapter. Nordhaus also took a relatively sophisticated approach to risk, but arrived at much lower estimates of damage costs, due mainly to the use of more conventional discount rates.

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Stern's approach to risk and uncertainty results in his aggregated damage cost estimates being higher than they would be otherwise, mainly because he adds weighting to the unlikely but catastrophic tail of the probability distribution. This still allows damage costs to be compared directly with mitigation costs in developing objectives for climate change policy. By contrast, others advocate setting objectives based solely on the climate risks. For example, the EU has an objective to limit the global average temperature change to less than 2°C above pre-industrial levels (Stern 2007c). Stern's approach would appear to be preferable in that it allows both costs and benefits to be considered in formulating policy objectives.

One consequence of the Review's treatment of risk and uncertainty is that it places significant importance on the confidence intervals that climatologists and others place on their estimates. For example, if, over time, the central estimate of the degree of warming remain unchanged, but the confidence interval narrowed, this would tend to reduce damage costs as modelled by Stern.

## 5.3 Equity weighting

### The Review's approach

Climate change is expected to have more severe impacts in developing than developed countries, as discussed in chapter 3. The influence of the high damage costs in developing countries on aggregate global costs is, naturally enough, muted by the relatively low levels of income in these countries. This applies to both market and non-market costs. As an example of the latter, the cost of increased mortality is lower in poorer countries because these costs are based on willingness to pay, which is obviously affected by income.

For Stern, there are strong ethical reasons for weighting the impacts on poorer countries more strongly. These relate both to concern for those in poverty and the developed world's historic responsibility for GHG emissions. The Review points out that others, such as Nordhaus and Boyer, and Tol adopt equity-weighting when aggregating climate change damage costs.

As discussed, the Review sets  $\eta$  equal to 1, which implies that a dollar of income is worth more to poor people than rich people. This parameter, therefore, could have been used for equity weighting in the Review's modelling. However, this was not done as it would have required calculating utilities separately for each region and then summing them. Stern explains that doing this 'was beyond the scope of this exercise, given the limited time available' (Stern 2007c, p. 182). What he does instead is make a simple adjustment to one of the results, based in part on the extent to which equity adjustment increases the damage costs reported in Nordhaus and Boyer (2000). Stern's headline result that damage from

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climate change may be equivalent to an average reduction in global per-capita consumption of up to 20 per cent, now and forever, is the result of this adjustment. The unadjusted modelling result was 14.4 per cent.

## Discussion

An obvious point to make is that rich countries do not generally weight the interests of poor countries as highly as Stern advocates. Stern might counter that historic responsibility for GHG emissions strengthens the ethical argument for doing so in the case of climate change.

Maddison presents an argument against equity weighting that was not addressed in the Review:

The argument against [the use of equity weights] in this context is that projects to cut carbon emissions should not be justified on distributional grounds when it is possible to make direct transfers compensating those who stand to lose from implementing or failing to implement cuts in GHG emissions. Another way of saying all this is that one should at least entertain the possibility that it might at the margin be cheaper to compensate the victims of climate change than abate GHG emissions. (Maddison 2007, p. 4)

Most of the Review's results are not equity-weighted and so those who regard equity-weighting as unjustified are able to concentrate only on these.

## 5.4 Aggregating the Review's estimates

### The Review's approach

Using the approaches to discounting over time and treatment of risk described above, Stern aggregates damage costs to 'balanced growth equivalents' (BGEs), rather than the more familiar net present value. The Review states:

... the BGEs calculated here calibrate the expected utility in a particular scenario (with many possible paths) in terms of the definite or certain consumption that, if it grew at a constant rate, would generate the same expected utility. One can, therefore, think of the BGE measure of climate-change costs ... as the maximum insurance premium society would be prepared to pay, on a permanent basis, to avoid the risk of climate change (if society shared the policy-maker's ethical judgements). (Stern 2007c, p. 185)

To illustrate, the BGE for the damage costs shown in figure 3.5a is 5.0 per cent and for figure 3.5b is 14.4 per cent. To put this another way, if the losses shown in figure 3.5a were in prospect then the global community, if it shared the Review's ethical judgements,

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should be prepared to pay up to 5.0 per cent of GDP, now and forever, to eliminate them. It should be noted that, while the figures end at the year 2200, Stern assumes that GDP will continue to be lower than it would have been without climate change after 2200 (chapter 3). It has been estimated that these post-2200 costs are responsible for more than 50 per cent of Stern's BGE estimates (Yohe and Tol 2007).

The BGEs for all six of Stern's scenarios are shown in the first column of figures in table 5.2. The remaining columns shows the results of sensitivity analysis conducted for a postscript to the Review.

As discussed in chapter 3, the Review essentially dismisses the 'baseline climate with market impacts only' scenario as being unrealistic. Accordingly, Stern uses the scenario assuming baseline climate and including market impacts and the risk of catastrophe as the lower bound estimate of damage costs in the Review's headline conclusion:

... if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5 per cent of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20 per cent of GDP or more.

In contrast, the costs of action — reducing GHG emissions to avoid the worst impacts of climate change — can be limited to around 1 per cent of global GDP each year. ... So prompt and strong action is clearly warranted. (Stern 2007c, p. xv)

The upper bound figure of 20 per cent is based on the scenario that assumes high climate and all impact categories. As shown in table 5.2, the BGE for this scenario is 14.4 per cent — as explained earlier, an adjustment for equity weighting is responsible for increasing this to 20 per cent.

The scenario assuming baseline climate and including all impact categories is described in the Review as the central case. Accordingly, the Review's central case estimate of the cost and risks of business-as-usual climate change is that they are equivalent to 10.9 per cent of global GDP each year, now and forever (table 5.2).

**Table 5.2 The Review’s aggregated damage cost estimates, by scenario and set of discounting parameters<sup>a</sup>**

Balanced growth equivalents (mean)

Climate	Impact categories	$\delta = 0.1$			$\eta = 1.0$		
		$\eta = 1.0$ ( $r_L = 1.4$ )	$\eta = 1.25$ ( $r_L = 1.7$ )	$\eta = 1.5$ ( $r_L = 2.1$ )	$\delta = 0.5$ ( $r_L = 1.8$ )	$\delta = 1.0$ ( $r_L = 2.3$ )	$\delta = 1.5$ ( $r_L = 2.8$ )
Baseline	Market impacts	2.1	na	na	na	na	na
	As above + risk of catastrophe	5.0	3.8	2.9	3.6	2.3	1.4
	As above + non-market impacts	10.9	8.7	6.5	8.1	5.2	3.3
High	Market impacts	2.5	na	na	na	na	na
	As above + risk of catastrophe	6.9	na	na	na	na	na
	As above + non-market impacts	14.4	12.1	10.2	10.6	6.7	4.2

<sup>a</sup> Where  $\delta$  is the pure rate of time preference,  $\eta$  is the elasticity of the marginal utility of consumption and  $r_L$  is the discount rate applying from 2200 onwards. Prior to 2200 discount rates vary across scenarios, paths and over time. **na** not available.

Source: Stern (2007c).

As explained in chapter 4, the Review’s mitigation cost estimate of 1 per cent of GDP per year is for stabilisation of atmospheric concentrations of GHGs at 500–550 ppm carbon dioxide equivalent (CO<sub>2</sub>e). At least initially this estimate relates to the year 2050. In various places (including chapters 9 and 13) the Review suggests that the costs could be lower than this initially and only build up to 1 per cent after several decades. Also, most of the macroeconomic modelling referred to by the Review shows mitigation costs increasing after 2050, as increasingly deep cuts to emissions are required (chapter 4). These potential variations in mitigation costs over time are not factored in to the Review’s headline conclusions. That is, there is no formal aggregation (discounting etc) of mitigation costs, they are simply estimated to be 1 per cent of global GDP per year on an ongoing basis. This is a shortcoming of the Review. Aggregation using Stern’s low discount rates may have increased the mitigation cost estimate, given the apparent likelihood of costs increasing after 2050.

## Discussion

### *The Review’s damage cost estimates are much higher than most others*

The Review’s estimates of the aggregated damage costs of climate change are much higher than most other estimates. This is most easily seen by comparing estimates of the marginal

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damage cost of GHGs (referred to in the Review as the social cost of carbon). This is because virtually all studies of climate change damage costs include such estimates, while most do not report BGEs. The marginal damage cost is the present value of damage costs from now into the future of emitting an extra unit of GHGs now. The Review's central case estimate is US\$312 per tonne of carbon (or US\$85 per tonne of carbon dioxide). This compares to a recent estimate by Nordhaus of US\$17 per tonne of carbon (Nordhaus 2006b). From a meta-analysis of 28 studies, Tol (2005) concluded that marginal damage costs are unlikely to exceed US\$50 per tonne of carbon, although a few of the estimates examined were higher than Stern's.

The Review's use of low discount rates is the main reason its aggregated damage costs are higher than most other estimates. Nordhaus reports that his estimate of US\$17 increases to US\$159 per tonne if Stern's discounting parameters are used. In approximate terms, Stern's estimate is 20 times higher than Nordhaus'. Differences in discounting account for a ten fold difference, while other factors account for a two fold difference. In Tol's meta-analysis the highest estimates tended to be the ones that used low discount rates (Tol 2005). The sensitivity of the Review's results to the discount rates used is shown in table 5.2. Increasing the pure rate of time preference ( $\delta$ ) from 0.1 to 1.5 per cent results in about a three fold decrease in damage costs.

#### *Further sensitivity analysis is informative*

Some authors and contributors to the Review have published a paper responding to various criticisms (Dietz et al 2007). On most issues, this paper defends the analysis presented in the Review. However, it appears to accept that some of the criticisms may have some validity. On some issues it presents sensitivity analysis to show the effect of changed assumptions on the central case estimate. Table 5.3 presents and comments on some of this analysis.

**Table 5.3 Further sensitivity analysis, relative to Stern’s central case damage cost estimate<sup>a</sup>**

<i>Issue</i>	<i>Sensitivity</i>	<i>Change in cost (BGE)</i>	<i>Comment</i>
Adaptive capacity	The Review assumes higher vulnerability to climate change in Africa, India, Southeast Asia and Latin America through to 2200. The assumption for the sensitivity analysis is that vulnerability in these regions instantly falls to that of the EU in 2100.	-1.5	The Review has been criticised for assuming that vulnerability in developing countries remains high even after living standards increase substantially. The reduced vulnerability in the sensitivity analysis seems more realistic.
Population growth	The Review extrapolates from the IPCC A2 scenario to give a global population increasing to 21.5 billion by 2200. The assumption for the sensitivity analysis is population growth that is reduced by 40%.	-4	The A2 scenario assumes population growth that is much higher than projections by the United Nations and others. The lower growth in the sensitivity analysis seems likely to be more realistic.
Relative price of environmental goods	The Review assumes that utility is only an aggregate function of total consumption. The assumption for the sensitivity analysis is that utility is a function of both consumption and environmental goods (in effect increasing the relative price of environmental goods).	+2	There are some reasons for expecting that the relative price of environmental goods will increase if per capita income increases and the environment deteriorates due to climate change. However, it is unclear whether the size of the change made for the sensitivity analysis is appropriate.

<sup>a</sup> Formal sensitivity analysis was conducted for ‘adaptive capacity’ only. The other results are described as ‘back-of-the-envelope’ calculations. Note that the effect of varying several parameters at once will not be additive.

Source: Dietz et al (2007); comments are by the authors of this paper.

***Not all of the damage costs can be avoided by mitigation***

In its conclusions, the Review compares estimates of total damage costs with mitigation costs. As has been pointed out by some critics, this is not the correct way to frame the issue (Yohe and Tol 2007). Mitigation costs should be compared with the damage costs they are expected to avoid, so as to predict whether there are net benefits from action.

While the Review’s conclusions are open to this criticism, the necessary information is provided in chapter 13. Stern’s mitigation costs are based on stabilisation of atmospheric concentrations of GHGs at 500–550 ppm carbon dioxide equivalent (this choice of stabilisation target is discussed in the next chapter). For the central case, Stern estimates damage costs with stabilisation at the top of this range as equivalent to a 1.1 per cent reduction in GDP now and forever. Subtracting this from 10.9 per cent of GDP, which is the BGE for business-as-usual emissions, gives an avoided damage cost equivalent to



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9.8 per cent of GDP. Accordingly, the difference between total and avoided damage costs is not large and does not make a material difference to the Review's conclusions.

### *Cost-benefit analysis for climate change has limitations*

The task undertaken by the Review involved modelling humanity's expected welfare from now to infinity, with and without climate change, and in the presence of great uncertainty about the impacts of climate change. This is, to put it mildly, a difficult task. Stern states that because of uncertainty about scientific and economic possibilities, models examining climate change:

... should be treated with great circumspection. There is a danger that, because they are quantitative, they will be taken too literally. They should not be. They are only one part of an argument. But they can, and do, help us to gain some understanding of the size of the risks involved, an issue that is at the heart of the economics of climate change. (Stern 2007c, p. 163)

Tol is even more cautious about the economic modelling of climate change:

... it is as yet unclear whether our research findings [on costs and benefits] are superior to our gut feeling. Having worked in the field for 15 years, I do not know. (Tol 2006, p. 2)

In Stern's view, another important part of the part of the argument is an appreciation of the disaggregated risks and damages of climate change:

It is the scale of these risks and an appreciation of the types and severity of damages involved that provide the *main case* for urgent and strong action to stabilize emissions below 550 ppm CO<sub>2e</sub>, when one considers that the risks can be very substantially reduced by an expenditure of around 1% of GDP per year. (Stern 2007c, p. 650)

However, Stern does not develop this argument in any formal sense, and it is difficult to see how this could be done in a way that was superior to a cost-benefit analysis. It would seem that there is little choice but to try to improve efforts at cost-benefit analysis, recognising the great uncertainties that exist.

Weitzman (2007) suggests that the greatest uncertainty in the economics of climate change is which discount rate to use. On this issue, Quiggin arrives at the following conclusion:

The real difficulty here is that we are pushing economic analysis to its limits, in an area where fundamental problems, such as the equity premium puzzle remain unresolved. Economists can help to define the issues, but it is unlikely that economics can provide a final answer. (Quiggin 2006, p. 18)

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## 5.5 Summary

Because climate change mitigation incurs costs now for benefits that are expected mainly in the very long term future, the choice of discount rates is critical. Uncertainty over the damage costs of climate change, and the likely distribution of these costs across people with different incomes, leads to further important aggregation issues.

Ethical considerations inevitably come into the choice of aggregation factors for climate change. Different ethical perspectives lead to very different results and policy prescriptions.

There are some plausible arguments for selecting discount rates for analysing climate change that are lower than those used in many other contexts. Even allowing for this, the rates used in the Review are low. The discount rates used in the Review are based on the authors' ethical judgements and are not designed to be representative of community preferences.

Stern builds a degree of risk aversion into the analysis. This is perhaps appropriate, given the large stakes at play.

The Review's headline conclusion (after aggregation) is that business-as-usual emissions involves costs and risks that are equivalent to losing at least 5 per cent, and up to 20 per cent, of global GDP, now and forever. These damage cost estimates are considerably higher than most others, and the use of low discount rates is the main reason for this. It appears that the discount rates used by the Review are around 1.4 per cent per annum. Adding one percentage point to the discount rates reduces the cost estimates by more than half.

Not all of the damage costs can be prevented. The Review concludes that mitigation actions costing 1 per cent of global GDP (+/- 3 per cent) each year could reduce damage costs to around one tenth of those for business-as-usual emissions.

There are great scientific and economic uncertainties in estimating aggregate damage and mitigation costs for climate change, including which discount rate to use.

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## 6 Climate change policy

The second half of the Review covers mitigation and adaptation policy as well as international collective action. This part of the Review has received much less comment than the estimates of damage and mitigation costs. This chapter gives a broad overview of this material, selecting some important issues for more detailed discussion.

### 6.1 Policy objective

In 1992, the international community of states adopted the United Nations Framework Convention on Climate Change (UNFCCC). Its objective is ‘to achieve ... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system’. Stabilisation ‘should be achieved within a timeframe 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’ (UNFCCC, Article 2).

However, this objective, almost universally accepted now with 190 countries having ratified the UNFCCC, has been criticised as being insufficient to guide climate change policies. Stern and other analysts have proposed overall objectives for climate change policy based on estimates of the cost, benefits and risks.

#### The Review’s approach

The Review emphasises the importance of developing a common understanding of the goal of climate change policy at the global level:

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. (Stern 2007c, p. 324)

#### *Mitigation objective*

The objective set for climate change mitigation could be in terms of temperature increases, atmospheric concentrations of greenhouse gases (GHGs) or cumulative emissions over a period. Stern opts for *stabilisation* of atmospheric concentrations, as this allows policy-

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makers to monitor progress in a timely fashion (unlike temperature increases, which are believed to lag human causation). Stabilisation implies that emissions will need to be reduced to very low levels in the long-term, as explained in box .

**Box 6.1      What does stabilisation mean?**

Climate change is a ‘stock externality’. This means that the temperature increase is determined by the stock, or concentration, of GHGs in the atmosphere. Since some gases have a long lifetime in the atmosphere (for example, 5 to 200 years for CO<sub>2</sub> and up to 3 200 years for sulphur hexafluoride), emissions over a long time horizon contribute to the stock.

The change in the stock of GHGs depends on the gap between emissions and the Earth’s natural capacity to remove them from the atmosphere.

This implies that stabilisation of the atmospheric concentration of GHGs (and of temperature increases) ultimately requires a reduction of emissions to the level of the absorptive capacity of the biosphere. Emissions currently are in the order of 40 to 45 gigatonnes (Gt) carbon dioxide equivalent (CO<sub>2</sub>e) per annum. The natural absorptive capacity is around 5 Gt CO<sub>2</sub>e per annum (Stern 2007c). Thus, stabilisation would require global emissions to be reduced by more than 80 per cent in the long run.

A clear implication of the scientific consensus that anthropogenic GHG emissions are very likely to have caused increases in global temperature is that further increases in temperature (and thus the damages from climate change) will depend on atmospheric concentrations. The Review says that the optimal stabilisation level for atmospheric concentrations can be chosen by comparing the marginal costs and benefits of changing the level. However, Stern points out that there are some difficulties in applying this approach, including:

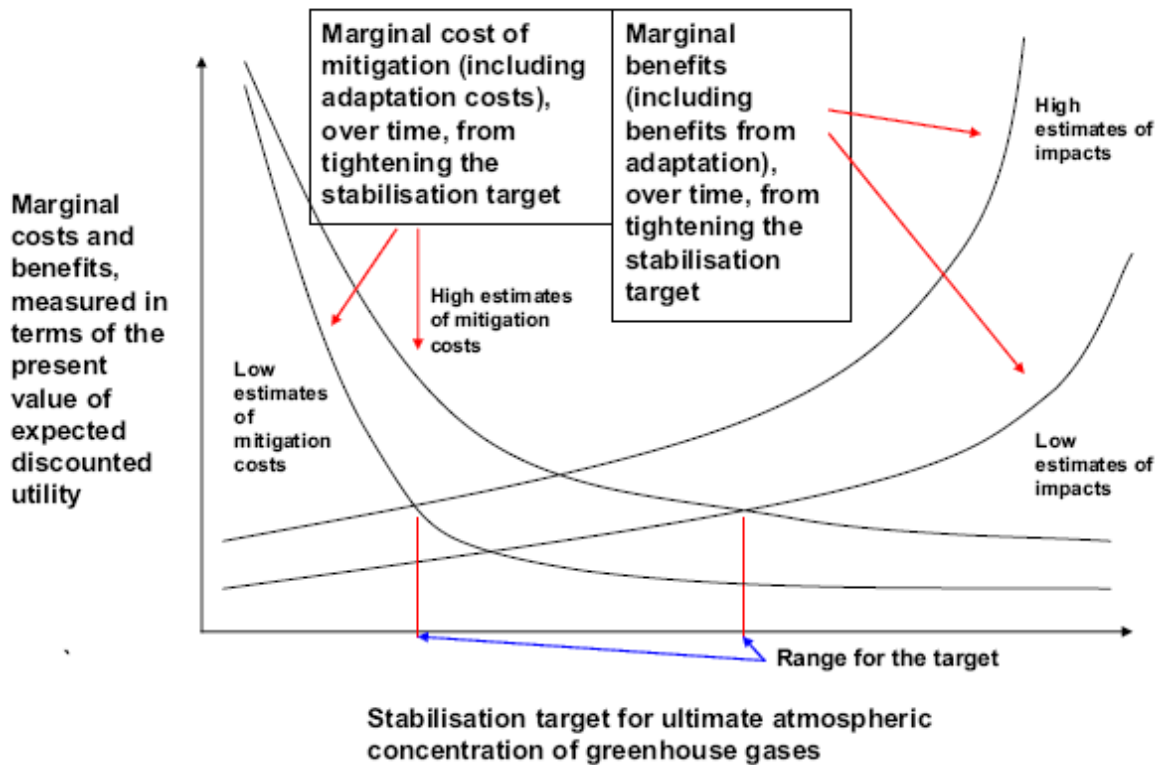
- the uncertainties surrounding climate science, climate-change damages and mitigation costs
- the uncertainty about socioeconomic and technological development over the long time horizon
- the ethical judgements that must be made concerning the weighting of damages over time and across countries.

The Review concludes that ‘given the uncertainty about both sides of the ledger, this approach cannot pin down a precise number but can ... suggest a range in which it should lie.’ (Stern 2007c, p. 328)

The approach taken in the Review for deriving a target range is illustrated in figure . Under certainty, the optimal level would be determined by the intersection of the marginal cost and benefit curves. Under uncertainty high and low estimates for these curves can be

identified. The upper range for the stabilisation target is determined by the most optimistic outcome for climate impacts (low estimate of impacts) and the most pessimistic case of mitigation costs (high estimates of mitigation costs) and vice versa for the lower bound.

Figure 6.1 Schematic representation of how to select a stabilisation level



Source: Stern (2007c).

### *The stabilisation range*

Stern suggests a range for the stabilisation target of 450 to 550 ppm CO<sub>2</sub>e. This is justified by identifying ‘turning points’ — concentrations at which the damage and mitigation costs are expected to increase rapidly:

... stabilisation at levels below 450 ppm CO<sub>2</sub>e would require immediate, substantial and rapid cuts in emissions that are likely to be extremely costly, whereas stabilisation above 550 ppm CO<sub>2</sub>e would imply climatic risks that are very large and likely to be generally viewed as unacceptable. (Stern 2007c, p. 219)

Based on both the disaggregated analysis of climate change impacts and the modelling of overall costs, the Review finds that damage costs increase steeply as concentrations increase beyond 550 ppm CO<sub>2</sub>e. The argument in essence, is that costs are likely to increase gradually up to a 2°C temperature increase (relative to the pre-industrial era), but increase rapidly beyond that. Above 4–5°C ‘the risks of experiencing some extremely

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damaging phenomena [such as the deaths of hundreds of millions of people due to food and water shortages] begin to become significant' (Stern 2007c, p. 331). Based on IPCC (2001c), at 550 ppm CO<sub>2</sub>e there is a 9 per cent chance of exceeding a 4°C increase in temperature and a 2 per cent chance of exceeding 5°C (the Review quotes higher probabilities based on some more recent scientific studies).

For mitigation costs, Stern points out that achieving stabilisation at 450 ppm CO<sub>2</sub>e would be difficult as it may involve replacing existing capital stock ahead of schedule. The high structural adjustment costs and possible social instability associated with very rapid cuts in emissions are discussed.

The Review estimates that stabilising atmospheric concentrations of GHGs at 500–550 ppm CO<sub>2</sub>e would involve ongoing mitigation costs equivalent to 1 per cent of GDP (+/- 3 per cent). Even taking the upper bound, this is less than the benefits as estimated for the Review's central case:

Our work with the PAGE model suggests that, allowing for uncertainty, if the world stabilises at 550 ppm CO<sub>2</sub>e, climate change impacts could have an effect equivalent to reducing consumption today and forever by about 1.1%. ... this compares with around 11% in the corresponding 'business as usual' case [baseline climate, all impact categories] – ten times as high. (Stern 2007c, p. 333)

That is, a cost of -2 to 4 per cent of GDP now and forever produces benefits equivalent to around 10 per cent of GDP, now and forever. On this basis, stabilisation at 550 ppm CO<sub>2</sub>e is clearly better than doing nothing. It is also implied that 550 ppm CO<sub>2</sub>e is a preferable stabilisation target than 650 ppm CO<sub>2</sub>e, as the equivalent consumption loss estimated for the latter is 0.6 per cent higher (although no estimate of the reduction in mitigation cost associated with the less stringent target is given).

The Review argues that, given the uncertainties, 'any long-term goal would need to be kept under review and adjusted as scientific and economic understanding developed' (Stern 2007c, p. 318).

### *Pathway to stabilisation*

The targeted stabilisation level does not determine the time path for emissions. For example, stabilisation at 550 ppm CO<sub>2</sub>e (without 'overshooting') would require global emissions to peak sometime in the next 10–20 years and then fall by around 1–3 per cent per year. The earlier the peak, the lower the required rate of reduction thereafter. And the less stringent the target, the more flexibility there is as to the time path. The pathways to stabilisation suggested in the Review are shown toward the end of this chapter in figure . It is not clear how these were derived as no optimisation exercise was undertaken. The main message is that achieving an early peak is difficult given the current trajectory of emissions, but has benefits in terms of reductions in subsequent mitigation costs.

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‘Overshooting’ refers to exceeding an atmospheric concentration target for a period, but eventually achieving the target. This would require global emissions to be less than the natural absorptive capacity of the biosphere for an extended period. Because of the radical cuts in emissions required, Stern says that it would be unwise to assume that any overshoot could be clawed back. And even if it were possible:

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.’ (Stern 2007c, p. 340)

### *Adaptation*

The Review discusses the role of adaptation in reducing the damage costs of climate change but does not formulate an adaptation objective. The Review’s approach to adaptation is discussed in section 6.3.

## **Discussion**

The Review reports on the results of studies that have used integrated assessment models to estimate the amount of mitigation that maximises benefits less costs.

- 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 800 ppm in 2100 to around 750 ppm, reducing global mean temperature from around 3.25°C above 1990 levels to around 3°C. (Stern 2007c, p. 337)

The striking thing about these results is how modest the recommended emission reductions are compared to those in the Review. The main reason for this is that these studies estimate business-as-usual damage costs from climate change to be relatively low (in present value terms). This in turn is due mainly, but not entirely, to the use of higher discount rates than those used by Stern (as discussed in chapter 5). In addition, the Review advocates a ‘flatter’ time path for emission reductions compared to the ‘policy ramp’ proposed by Nordhaus and others who use more traditional discount rates (Barker 2007). The studies also vary in their assumptions about the likely growth in atmospheric concentrations of GHGs under business-as-usual.

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Another point of difference is that while the Review proposes a stabilisation target range, these other studies do not. Presumably, for these analysts decisions about stabilisation should be left to the longer term future. It is also the case that Nordhaus and Boyer, and Tol derive the optimal amount of mitigation within their modelling, while the Review takes a heuristic approach. Stern's contention is that optimisation analysis 'would demand too much of formal modelling and probabilistic forecasts, which project hundreds of years into the future' (Dietz et al 2007, p. 168).

The above studies were all published in the 1990s. Some more recent work shows higher levels of mitigation to be optimal. For example, Nordhaus' most recent results using the DICE model are that the optimal global mitigation effort reduces atmospheric concentrations of carbon dioxide from 683 ppm in 2100 to 588 ppm (a reduction of 95 ppm, compared to the reduction of 19 ppm quoted above) (Nordhaus 2007). Despite this, the difference between the amount of mitigation proposed by Stern and that proposed by Nordhaus remains large. Both agree, however, that policies that go far beyond current global emissions reductions are warranted (Nordhaus 2006b).

## 6.2 Mitigation policy

Chapters 14–17 of the Review are devoted to various aspects of mitigation policy.

### The Review's approach

The Review gives the essential elements of climate change mitigation policy as:

- an emissions price
- technology policy
- policies to address barriers to behavioural change.

It argues that leaving out any of these elements will significantly increase the mitigation costs.

#### *Emissions price*

Of the three elements, the Review places most emphasis on emissions pricing, which it says could be achieved explicitly through taxes or tradeable quotas, or implicitly through regulation. The Review argues that emissions pricing needs to have the following characteristics.

- Environmental effectiveness — the trajectory of emissions prices over time should be consistent with achieving the policy objective.



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- Efficiency — the price signal should reflect the marginal damage cost caused by emissions, and rise over time to reflect the increasing damages as the stock of GHGs grows.
  - Cost-effectiveness — emissions prices should be, as far as practicable, equivalent across sectors, GHGs and countries. A degree of price stability is also required to achieve cost-effectiveness over time.
  - Credibility — firms must believe that emissions prices will endure before they fully factor them into long-term investment decisions, such as those relating to power stations, and research and development into low-emissions technologies.
  - Flexibility — the pricing policy should be able to change in response to new information.
  - Predictability — there need to be clear revision rules that set out the circumstances and procedures under which the pricing policy would change.

The Review discusses the likely impacts on industrial location if countries move at different speeds on emissions pricing (or other mitigation policies). The conclusion is that this is unlikely to be a major problem because there are generally more important determinants of firm location, such as workforce characteristics and access to technologies and infrastructure.

### *Technology policy*

The Review acknowledges that in ‘the absence of any other market failures, introducing a fully credible carbon price path ... would theoretically be enough to encourage suitable technologies to develop’ (Stern 2007c, p. 394). It goes on to say, however, that these conditions do not hold in practice, because:

- innovation produces spillover benefits and this causes it to be undersupplied
- it is not possible to achieve 100 per cent credibility for emissions pricing, particularly initially
- private sector firms and capital markets may be unwilling to take the risks associated with developing a new technology over an extended period (leading to ‘lock-in’ of existing technologies)
- there are subsidies for fossil fuel use, particularly in developing countries, and these discourage the development of low-emission technologies
- the nature of competition within some markets is not conducive to innovation (due to the existence of only one or a few firms and/or a risk that government regulation will prevent innovators from reaping the full benefits of innovation).

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Accordingly, Stern sees an important role for policies to support technological innovation. The aim of policy being to bring a portfolio of low-emission technologies to commercial viability, not to simply focus on those closest to commercialisation.

The Review considers policies to promote research, development and demonstration separately from those to promote deployment. On the former, the Review regards governments as having an important role in directly funding skills and basic knowledge creation for science and technology. While advocating governments be cautious about picking winners, energy storage, photovoltaics, biofuel conversion, fusion, material science and carbon capture and storage are identified as areas with large potential. It is recommended that global public energy funding be doubled, to around US\$20 billion per year.

The Review says that there are strong arguments for governments supporting the deployment of low-emissions technologies. This can be done through various means including subsidies, quota-based schemes and price support mechanisms (Australian examples include the Mandatory Renewable Energy Target scheme and subsidies for rooftop solar electricity generation). It is suggested that deployment incentives for low-emissions technologies be increased two to five times from current levels of around US\$33 billion per year.

### *Barriers to behavioural change*

The Review says that even if emissions pricing and support for the development of technology are introduced, ‘barriers and market imperfections may still inhibit action, particularly on energy efficiency’ (Stern 2007c, p. 427). For example, households and firms sometimes do not take up energy efficiency opportunities even when it would be cost effective for them to do so. Stern argues that both standard economic theory, and systems and behavioural theories of decision making are relevant to understanding the barriers to behavioural change.

The Review is generally supportive of policy responses to these barriers, although it points out that there can be hidden costs and benefits that mean that some energy efficiency opportunities may not be as attractive as they might appear. Policy measures identified as having potential include:

- minimum energy performance standards for buildings, appliances and cars
- labels, certificates and endorsement to raise the visibility of energy costs in investment decisions (for example, for domestic lighting, consumer electronics, white goods, electric motors, boilers, air conditioners and office equipment)
- requiring that customers be provided with informative energy bills, real time electricity displays and/or smart meters to enable them to better manage their energy use

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- integrated land-use planning to reduce transport demand
  - simplifying planning rules for the installation of micro-generation technologies
  - measures to raise the energy efficiency of government operations
  - government initiated education, persuasion and discussion to shape preferences and behaviours.

## **Discussion**

The Review provides an informative discussion of many mitigation policy issues. It argues that both economic principles and national circumstances (including political institutions and traditions) should inform the design of mitigation policy. Accordingly, there is a tendency not to be prescriptive on the choices individual countries should make. This is consistent with Stern's desire to build a coalition for action. Ultimately, the Review seems more concerned with being critical of inaction than criticising the types of action various countries might choose to take. Because of this, some opportunities to draw a distinction between good and bad policy are missed.

The arguments presented on policy design are generally grounded in mainstream economic thought. On some questions, however, the position taken conflicts with the views of some other analysts. Some of the most important of these are considered below.

### *Emissions trading or emissions taxes?*

This issue has both an international and a national dimension. An international framework for action on climate change could be based on either emissions trading or an emissions tax. Under a framework based on emissions trading, participating countries take on an emissions 'cap' or 'target'. This can be met through reducing emissions within the country or purchasing rights to emit from other countries. An emissions tax would be levied by individual countries at an internationally harmonised level.

If an internationally harmonised tax were introduced, participating countries would not have a choice as to the policy instrument they use at the national level. An international emissions trading framework, however, does allow participating countries the freedom to achieve their targets with whatever instruments they deem appropriate. A policy package could comprise national or international firm-level emissions trading, emissions taxes, support for research and development, subsidies or command and control measures (PC 2007).

This policy flexibility at the national level is one of the main reasons that the Review supports an international framework being based on emissions trading. The Review is not prescriptive about which policy instruments should be used at the national level, arguing

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that the choice should be influenced by national circumstances. Those that prefer an internationally harmonised emissions tax, such as Nordhaus (2006a) and Stiglitz (2006), see price stability as one of the main considerations. With a tax the emissions price is controlled, whereas with trading emissions are controlled and the emissions price may rise to levels that impose high costs on the economy.

Another group of analysts have proposed ‘hybrid schemes’ that combine qualities of both emissions trading and emissions taxes (Roberts and Spence 1976; Weitzman 1978; Kopp et al. 1997; McKibbin and Wilcoxon 1997; Jacoby and Ellerman 2002). These are essentially emissions trading schemes that set a ceiling to the permit price.

A discussion of the various economic efficiency, equity and political reasons for preferring one approach over the others at the international and national levels is beyond the scope of this chapter. Interested readers can find such a discussion in PC (2007).

### *How should the credibility of pricing policy be established?*

Like Stern, many other analysts also stress the importance of establishing the credibility of emissions pricing policy. McKibbin and Wilcoxon (2006, p. 2), for example, state:

... the actions that individuals and firms will need to undertake in order to reduce emissions involve enormous investments in capital equipment and research and development, both with long payback periods. A climate policy will be unable to induce such investments unless it is clear that the policy is likely to be enforced, and is unlikely to be repealed. The single most important characteristic of a climate policy, in other words, is to provide a solid foundation for large, long-term investments by the private sector.

Helm, Hepburn and Mash (2003) argue that climate change policy is prone to a lack of credibility because governments face a time-inconsistency problem. That is, because of conflicting objectives, they have an incentive to renege on climate policy commitments once investment costs are sunk. Knowing this, firms may decide not to invest in emissions reduction. For example, where a government has announced both an emissions reduction target and an objective to keep energy prices low, firms may consider it likely that the latter will eventually take precedence and, therefore, view the climate change target as non-credible.

McKibbin and Wilcoxon (2006) illustrate the importance of policy credibility. They show that if a permit to emit one tonne of carbon costs \$20, a firm may be prepared to invest up to \$400 to reduce their annual permit requirements by one. However, if the firm believes that there is a 10 per cent chance each year that the policy will be repealed the investment incentive can drop by two-thirds, to \$133.

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While many analysts recognise the importance of this issue, they are divided on how best to deal with it.

The Review advocates building the credibility of emissions pricing by setting long-term emissions targets (with clear revision rules), avoiding destabilising influences (such as premature inclusion of forestry offsets in carbon markets) and encouraging stakeholder support for policy. It considers that whether emissions trading is more or less credible than emissions taxes is not clear, and depends on national circumstances. There is a need to recognise that, whatever the instrument, establishing credibility will take time and so ‘[d]uring the transition period, governments should consider how to deal with investments in long-lived assets which risk locking economies into a high-carbon trajectory’ (Stern 2007c, p. 368). The emphasis that the Review places on technology and energy efficiency policy is motivated in part by the belief that it will take time to establish the credibility of emissions pricing.

McKibbin and Wilcoxon (2006, p. 3) argue that establishing the credibility of climate change policy requires creating:

... a constituency with a strong financial interest in perpetuation of the policy. Bluntly put, it must create a powerful lobby group that will vigorously resist any attempt at backsliding by future governments.

They regard emissions taxes as having the opposite effect, as all future users of fossil fuels would be motivated to lobby against them. The policy they advocate is a form of emissions trading with a ‘safety valve’ on price (often referred to as a hybrid system). A distinctive feature of their proposal is that there be no international trade in emission permits. One reason they see such trade as undesirable is because poor monitoring and compliance in one country could debase the entire global trading system. Without trading, any such problems would be confined to individual countries. Further, within each country the constituency of permit holders would pressure their government to enforce compliance and monitor vigilantly in order to maintain the market value of permits. In their view, not allowing international trade increases the credibility of emissions pricing and this advantage outweighs the potential gains from trade.

Montgomery and Smith (2005) essentially see the credibility problem of emission pricing as unsolvable. They regard the main task for climate change policy as creating the conditions necessary for the development of new low-emissions technologies. They argue that emissions pricing policies are unable to create these conditions:

What the literature has failed to recognise is the impossibility of creating a credible announcement of a future [emissions] limit or carbon price at a level sufficient to motivate research and development investment by the private sector. (Montgomery and Smith 2005, p. 17)

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They stress that, for efficiency reasons, emissions prices should start off at a low level and increase substantially over time. In the case of an emissions tax, they regard future increases sufficient to stimulate the necessary research and development now as non-credible. This is because governments will always have an incentive to not proceed with planned increases once innovation has occurred. For emissions trading, they argue that competition will drive permit prices down to a level that does not allow innovators to recoup their investment. Accordingly, Montgomery and Smith argue that government support for research and development should be the main focus of climate change policy, with emissions pricing given only a minor role (this is sometimes referred to as a ‘technology-push’ approach).

In considering national climate change policy, Helm, Hepburn and Mash (2003) propose an institutional solution to the issue of credibility. They point out the time-inconsistency problem at play is also found in other areas, including monetary policy. They say that the lessons that have been learned from the setting of monetary targets and interest rates provide useful insights for climate change policy. For monetary policy, the delegation to an independent central bank is the conventional solution. For climate change policy, they advocate the creation of an energy agency with two objectives — meeting a GHG emissions target (possibly with the policy instrument specified by the government) and a security-of-supply target (possibly using a capacity payment instrument).

Another theme in the literature is that policy credibility is unlikely to be higher than the credibility of the science of climate change (Montgomery and Smith 2005). If people have strong doubts that climate change will prove to be as big a threat as forecast, they will tend not to base their long-term decisions on the premise that emissions prices will rise over time. Similarly, policy credibility in an individual country is dependent on the credibility of international policy. This is because it is unlikely that a government would continue to increase national mitigation costs in the absence of effective policies in other countries. In fact, some governments signal this in advance by making their long-term emission targets conditional on commensurate international efforts.

*If emissions pricing and support for research and development are introduced, is deployment support also required?*

As discussed above, the Review recommends that governments give considerable support to the deployment of low emission technologies, in addition to emissions pricing and support for research and development. This contrasts with some other analysts who regard the rationale for deployment support as weak (Montgomery and Smith 2005; Nordhaus 2004).

The Review argues that even where a new technology has the potential to become cost effective in time, it may not be deployed because firms (and/or capital markets) are

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unwilling to bear the ‘learning costs’ in the initial years (learning costs being how much more the new technology costs than the existing technology). This is described as ‘an industry version of a collective action problem with its associated free rider issues’ (Stern 2007c, p. 397). This problem, it is argued, can lead to ‘lock-in’ of existing technologies. Stern maintains that the power generation sector is particularly prone to technology lock-in due to high learning costs, the nature of the distribution infrastructure, subsidies to fossil fuel use and other factors.

The appropriate response, according to the Review, is for governments to increase support for the deployment of low emission technologies so as to promote learning-by-doing. It suggests that globally this support be around US\$91 billion in 2015 and US\$163 billion in 2025. This implies that deployment support would be the *main* component of climate change policy for the next decade or more, with emissions pricing taking over this position after that (Anderson 2006).

The argument for government deployment support can only be valid if two conditions hold. First, there must be a reasonable expectation that valuable learning will be realised. Montgomery and Smith conclude that this is not the case at present because:

... the needed technologies simply do not exist today, so that learning-by-doing with existing technologies will not contribute to development or reduction in the cost of the needed technology. (Montgomery and Smith 2005, p. 16)

They argue that near term emission reductions are best achieved through the increased deployment of mature technologies, such as electricity generation using gas rather than coal. And that support for low-emission technologies should be directed to research and development, rather than deployment. If their view is correct, the net result of having deployment support in addition to a cap-and-trade scheme would be higher mitigation costs.

The second necessary condition is that there must be some substantial market failure, amenable to government correction, that prevents firms from appropriating the value obtained from learning. The Review argues that there is, but this view is contested. Nordhaus for example, maintains that the historical evidence is that learning-by-doing is largely firm-specific. For this and other reasons he concludes that at present ‘it would be folly to rely upon learning-by-doing to rationalise a costly or critical component of climate change policy’ (Nordhaus 2004).

It is not clear whether Stern regards a strong reliance on deployment policy as ideal, or simply necessary given current arrangements and political constraints on policy choices in various countries. What is clear is that deployment support has the potential to increase mitigation costs significantly and unnecessarily (PC 2007). Accordingly, any proposal for its use should be thoroughly evaluated.

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## 6.3 Adaptation policy

The Review includes three chapters that cover various aspects of adaptation.

### The Review's approach

The definition of adaptation used by the Review 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’ (IPCC 2001a). According to the Review, adaptation is the only way to deal with the unavoidable impacts of climate change to which the world is already committed. However, although adaptation can mute climate change impacts, it cannot entirely remove them, and it incurs costs. The relative effectiveness of adaptation is expected to diminish and its cost to increase as the magnitude and speed of climate change increases. Hence, the Review argues that without early and strong mitigation the costs of adaptation will rise sharply and residual climate change damage after adaptation will be large.

The Review points out that an important difference between adaptation and mitigation is the incidence and timing of benefits — adaptation provides local benefits without long lag times, whereas mitigation provides global benefits which take longer to arise. As such, some adaptation is expected to occur autonomously. However, there are barriers that may hinder autonomous human adaptation. Those discussed include:

- uncertainty and imperfect information about climate change projections, which makes it difficult to assess the costs and benefits of adaptation
- missing and misaligned markets (including public goods), which make it difficult to assure those paying the current costs of adaptation that they will reap the full benefits
- financial constraints to upfront investment.

The Review argues that, in developed countries, governments have a role to play in addressing these barriers in four key areas.

- The provision and effective communication of high-quality information, particularly improved regional climate predictions.
- Land-use planning and performance standards (for example, structural requirements for new buildings) to encourage proper pricing of climate change risk into long-term investment decisions.
- Long-term policies for climate-sensitive public and publicly-provided goods, for example, natural resource and flood protection, to avoid significant public liability if disaster recovery and public safety costs rise sharply.



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- Financial support for the poorest in society, particularly if risk-based insurance systems are in place that may be unaffordable for those on low incomes. (The Review is not optimistic about the insurance industry's ability to bear sharply rising damage costs.)

The Review argues that the foundation of adaptation policy in developing countries should be good development policy. This involves:

- promoting development broadly (for example, through economic diversification and investment in health and education)
- enhancing resilience to disasters and improving disaster preparedness and management
- promoting risk sharing approaches through insurance and pooling of disaster risks (and encouraging private sector involvement in these areas)
- developing social safety nets.

The Review also discusses the role of new policies to encourage adaptation by private agents in developing countries. Similar policies to those required in developed countries will be needed (outlined above). However, their application will differ due to development constraints.

## Discussion

Most of the Review's conclusions regarding adaptation policy are uncontentious. In particular, it is generally agreed that it is optimal to use both adaptation and mitigation strategies in responding to climate change (Ingham et al 2005; McKibbin and Wilcoxon 2003; Tol et al 1998).<sup>1</sup> The IPCC notes:

Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation essential ... Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt. (IPCC 2007a, p. 20)

It is also generally agreed that the market failures associated with adaptation are less pervasive than those for mitigation. This is because adaptation delivers local benefits that can often be appropriated by those taking the action. Further, to the extent that government intervention is required, action can be effectively taken at the national level.

One area of contention is whether policy frameworks for mitigation and adaptation should be integrated or treated as separate. According to McKibbin and Wilcoxon (2003),

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<sup>1</sup> In the literature, adaptation and mitigation are often referred to as being 'complementary'. Ingham et al (2005) show that in economic terms, adaptation and mitigation are substitutes. Only when the effect of mitigation on marginal adaptation cost is strong are mitigation and adaptation complements (that is, increasing mitigation costs reduces both mitigation and adaptation).

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institutions, regulations and markets should be designed in such a way as to deliver appropriate incentives to reduce climate change impacts through abatement as well as adaptation — policies such as mandated abatement targets will only give appropriate outcomes ‘by accident’, as the trade-off between abatement and adaptation is not dealt with. Ingham (2006) notes that, in determining the optimal level of mitigation, an assumption about the level of adaptation needs to be made. However, it should not be assumed that this is the optimal level of adaptation — the two should be determined jointly on the basis of relative costs and benefits. Wilbanks et al (2003) argue that integrating research into, and policy analysis of, mitigation and adaptation will provide protection at lower cost, due to the ‘synergies’ created. On the other hand, Berkhout (2005) argues that differences between the two policies pose challenges for their integration,<sup>2</sup> and Klein et al. (2003) conclude that the two policies should be kept separate — focusing on integration will encounter institutional complexity that could limit the policies’ efficacy. Although the Review argues that mitigation and adaptation should go ‘hand-in-hand’, it does not discuss an integrated policy framework.

## 6.4 International collective action

International collective action receives considerable attention in the Review, with seven chapters devoted to it.

### The Review’s approach

As mentioned previously, the Review identifies three essential elements of climate change mitigation policy — an emissions price, technology policy and action to address barriers to energy efficiency. Achieving these elements of policy on a global scale will require international collective action. The Review sets out some of the desirable features of collective action. Particular emphasis is placed on methods to encourage participation, and on prospective burden-sharing arrangements between developed and developing countries. Also discussed is the potential to build on existing arrangements for international action on climate change.

According to the Review, existing arrangements for international collective action — in particular the Kyoto Protocol — embody the key principles of a multilateral response and provide a good basis for future cooperation. The Review discusses flaws in the Kyoto

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<sup>2</sup> In addition to differences in the temporal and spatial scales on which they are effective, mitigation and adaptation differ in the extent to which their costs and benefits can be determined, compared and aggregated, and the actors and types of policies involved in their implementation (compared to adaptation, the number of sectors and actors involved in mitigation is limited).

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Protocol, but nevertheless concludes that the Protocol is a valuable starting point for international cooperation. The Review suggests that improvements could be made by:

- expanding the time horizon by introducing a long-term timetable for emissions reductions
- improving the mechanisms (such as the Clean Development Mechanism) through which developing countries participate, leading ultimately to these countries taking on binding commitments to reduce emissions
- redesigning the compliance arrangements so as to encourage ongoing participation.

Stern sees a global emissions price as the central element of international action and says that creating ‘a transparent and comparable carbon price signal around the world is an urgent challenge’ (Stern 2007c, p. 530). As discussed in section 6.2, the Review advocates establishing this price using emissions trading rather than a harmonised emissions tax. International aviation and shipping are identified as important targets for inclusion.

While a global emissions price should be the central part of global action, Stern also sees a need for international action to extend to other elements of climate change policy. According to the Review, international technology cooperation will be worthwhile to ensure a diverse portfolio of research and development activities across the globe, and to address the global public good nature of research and development. Further, regulations and product standards on energy efficiency should be internationally coordinated to address barriers in markets for energy efficiency. Recognising the different dimensions of countries’ actions on climate change will also be important. For example, countries that make a disproportionately large contribution towards technological development should be recognised for this effort, even though it will not be possible to translate this into an equivalent amount of emissions reductions.

The Review identifies forestry as an important sector that is not yet suitable for inclusion in the emissions pricing framework. There is more carbon presently locked up in forest ecosystems than in the atmosphere (IPCC 2001a) and preventing deforestation can be a highly cost-effective way of reducing GHG emissions. In the long-term, the inclusion of deforestation (and the planting of new forests) in carbon markets is seen as an effective way to support large-scale action. However, doing this too soon could destabilise carbon markets. In the interim, the Review says that alternative methods to discourage deforestation should be pursued, and the international community should compensate the (mainly developing) nations where the forests stand.

Another area where the Review calls for international support for developing countries is adaptation. Stern says that: ‘the poorest developing countries will be hit earliest and hardest by climate change, even though they have contributed little to causing the problem’ (Stern 2007c, p. 622).

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### *Participation and burden sharing*

The key challenge identified by the Review is to devise an agreement, or set of agreements, that attracts wide participation. Action on climate change has the potential to suffer from the ‘free rider’ problem: most individual countries are responsible for only a small share of total emissions, so their involvement in mitigation action will have little effect on total global emissions and, as such, they might be tempted to ‘free-ride’ on the efforts of other countries. To encourage wide participation, Stern advocates:

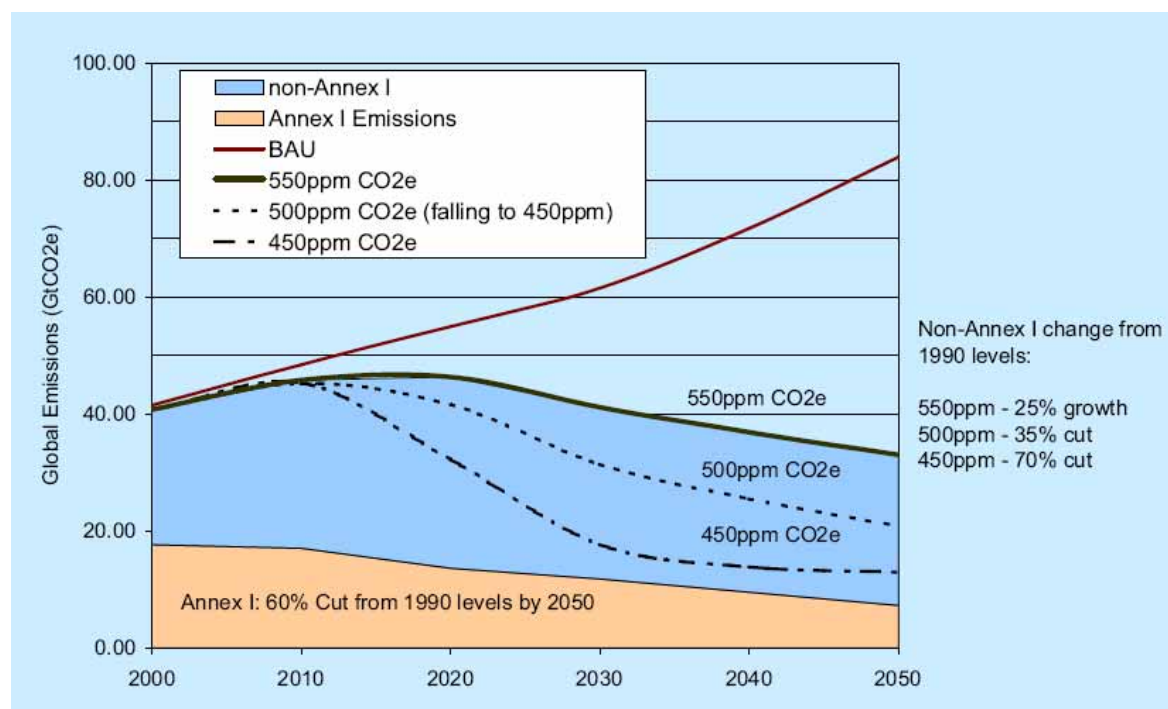
- developing a shared understanding of the goals of action
- aligning short-term goals, such as reduced air pollution, with long-term climate goals
- ensuring the transparency and comparability of national action
- careful design of compliance mechanisms
- ensuring an equitable distribution of effort across developed and developing countries.

With regard to the last point, the Review identifies a need for emission cuts across developed and developing countries because the scale of action necessary cannot be met by action in developed countries alone. For example, if developed countries reduce their emissions by 60 per cent from 1990 levels by 2050, action will still be needed in developing countries to reduce their growth in emissions to 25 per cent if the Review’s stabilisation target is to be met (figure ).

The Review argues that developed countries should take a greater share of mitigation costs because of their greater ability to pay, responsibility for a greater share of historical emissions and higher per capita emissions. This is consistent with the UNFCCC principle of ‘common but differentiated responsibilities’. The Review suggests, as an illustration, that if mitigation costs are 1 per cent of global GDP, the richest 20 per cent of the world’s population might agree to pay 1.2 per cent of GDP, leaving the poorer 80 per cent of people to shoulder costs equivalent to 0.2 per cent of GDP.

While equity is often deemed to require that developed countries pay a greater share of costs, efficiency demands that part of this will involve their taking responsibility for emissions reductions in developing countries. The Review states that ‘a major advantage of emissions trading schemes is that they enable efficiency and equity to be considered separately’ (Stern 2007c, p. 536). Through arrangements such as the Clean Development Mechanism (CDM) under the Kyoto Protocol, developed countries can take responsibility for emissions reductions in developing countries that are cheaper than those available in their own countries. Stern says that the CDM has played a valuable role in building cooperation between developed and developing countries.

Figure 6.2 Emissions reductions in developed and developing countries



<sup>a</sup> This figure shows the change in GHG emissions for non-Annex 1 (developing) countries that would be consistent with meeting various stabilisation targets — assuming that Annex 1 (developed) countries took responsibility for cuts equal to 60 per cent of their 1990 emissions by 2050.

Source: Stern (2007c, p. 520).

## Discussion

The Review does not lay out a fully specified ‘blueprint’ for collective action on climate change, but rather discusses the issues and outlines some desirable features for an international framework. That said, there are some issues on which a position is taken that is contested by others. The Review identifies some commonly described faults of the Kyoto Protocol, but suggests building on this framework. Others argue that the Protocol’s faults are so serious we should start from scratch. Further, the Review argues that the post-2012 international framework should be based around binding emissions caps for individual countries that:

- are consistent with a long-term stabilisation target for atmospheric concentrations of GHGs
- can be met in part through international trading in emission permits.

There are at least three groups that disagree with this position. Those that:

- believe it is unrealistic to insist on a nexus between country-based caps and a predetermined overall target (for example, Inquit 2007)

- 
- say that international trading in permits is undesirable (for example, McKibbin and Wilcoxon 2006)
  - see an internationally harmonised tax on emissions as preferable to a cap-and-trade architecture (for example, Nordhaus 2006a).

The issue that tends to dominate the geo-political debate, that of the treatment of developing countries, is singled out for a more detailed discussion below.

*How should developing countries be included in international agreements on climate change?*

Developing countries currently account for close to half of total global emissions of GHGs and the proportion is rising. Also, it has been reported that the majority of low cost abatement opportunities are in these countries (Enqvist, Naucler and Rosander 2007). Because of this, it is widely acknowledged (including by Stern) that broad participation by developing countries is essential for climate change mitigation to be effective and efficient.

Developing countries' participation was a major issue in past negotiations. Most developing countries have ratified the Kyoto Protocol but are not required to take on binding emissions targets. Under the Protocol's CDM, developed (Annex 1) countries may earn credits towards meeting their targets by implementing projects in developing countries.

The nature of developing country involvement was one reason why the United States and Australia decided not to ratify the Kyoto Protocol. In addition, the US Senate has unanimously passed the 'Byrd-Hagel resolution' ('S. Res. 98'), which proclaims that 'the United States should not be a signatory to any protocol ... [which mandates] commitments to limit or reduce GHG emissions for the Annex I parties, unless the protocol ... also mandates new specific scheduled commitments ... for Developing Country parties within the same compliance period ...' (Müller 2005).

From an economic perspective, approaches like the CDM are inferior to developing countries taking on binding commitments in two main ways. First, the CDM provides credit for emission reductions deemed to be beyond those expected under business-as-usual. Verifying such reductions is difficult, often costly and potentially open to gaming, because the business-as-usual baseline is hypothetical and so can not be established with any certainty. Second, the CDM does not internalise the cost of the GHG externality for firms and consumers in the host country or for goods exported from the country. Accordingly, the desired economywide emissions price signal is not achieved.

The Review acknowledges these shortcomings and argues that, in the longer-term, developing countries must incorporate the externalities of using carbon into the structure of

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incentives in their own economies. However, it appears to support the continued use of the CDM for a considerable period of time. Indeed, ways to improve the CDM are discussed at some length.

By contrast, some other analysts have suggested ways in which developing countries can adopt binding targets without this imposing large costs on them. Olmstead and Stavins (2006, p. 35), for example, state:

On the one hand, for purposes of environmental effectiveness and economic efficiency, key developing countries should participate. On the other hand, for purposes of distributional equity (and international political pragmatism), they cannot be expected to incur the consequent costs. The answer is a set of ‘growth targets’ that are set initially at business-as-usual levels for respective developing countries, but become more stringent as those countries become more wealthy.

Proposals of this type seem to have some potential for overcoming current political barriers to broader participation and improving policy effectiveness and efficiency.

## 6.5 Summary

The Review calls for strong, early action on mitigation so as to put the world on a path toward eventual stabilisation of atmospheric concentrations of GHGs at between 450 and 550 ppm CO<sub>2</sub>e. Most other economic analysts conclude that mitigation efforts should start off at much more modest levels and intensify over time (the ‘policy ramp’). The policy ramp approach, as advocated by Nordhaus and others, implies less mitigation overall compared to the Review. There is, however, widespread agreement that some mitigation action should be taken now.

According to the Review, the three essential elements of policy for mitigation are:

- an emissions price, preferably equalised across countries, achieved through tax, trading or regulation (with countries possibly taking different approaches)
- support for the development of a range of low-carbon technologies
- removal of barriers to behavioural change, particularly to encourage the uptake of opportunities for energy efficiency.

The Review tends not to be prescriptive about the choice of policy instruments, although it does support an international agreement being based on emissions trading, rather than emissions taxes.

How best to establish the credibility of emissions pricing policy into the future is a key issue on which views differ. Without such credibility, firms are unlikely to take emissions prices fully into account in their long term investment decisions. The Review advocates

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building credibility over time, and in the interim giving non-pricing policies a greater role than would otherwise be justified. Various other analysts have developed alternative strategies. Also, the Review's conclusion that there are strong arguments for government support for the deployment of low emissions technologies is contested by others.

The Review finds that preventing deforestation is often a low-cost means of reducing emissions. One way to create incentives for this is to allow credits for avoided deforestation in emissions trading markets, but Stern thinks that this could destabilise these markets.

The Review argues that policies to facilitate adaptation to climate change are essential, but not a substitute for mitigation.

The Review says that there are compelling reasons for developed countries to take on most of the costs associated with tackling climate change. This could involve these countries investing in emission reduction activities outside their own borders. The Review suggests improving the Kyoto Protocol's CDM to facilitate this, but regards it as essential that developing countries eventually take on binding emission constraints. Some other analysts have suggested ways in which developing countries could take on binding emission commitments without incurring large costs. These proposals seem to have some advantages over continued use of the CDM.



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# A Discount rates

There is a long standing debate on how to choose appropriate discount rates for public policy evaluation. One issue is how to deal with the fact that the resource costs of the policy may displace investment, current consumption or a combination of the two. More fundamentally, there is argument over whether a descriptive approach (that begins with evidence from decisions people make) or a prescriptive approach (that begins with ethical considerations) should be taken, particularly where long time horizons are involved. This appendix examines these debates and the implications for the choice of discount rates for use in analysing climate change.

## A.1 Investment and consumption sourcing

If undertaking a project draws resources away from an alternative investment, the returns that could have been earned on this investment are an opportunity cost of proceeding with the project. In these circumstances the rate of return of the alternative investment (after adjusting for differences in risk), termed the opportunity cost of capital (OCC), is an appropriate discount rate to use for analysing the project.

Alternatively, if the costs of a project displace current consumption, the future benefits should be at least high enough to compensate for the fact that people tend to prefer consumption sooner rather than later. That is, to voluntarily forgo a unit of consumption now, most people would require compensation of more than one unit of consumption in the future. Finding out just how much more allows peoples' rate of time preference to be calculated. In these circumstances the discount rate for the project could be derived from the rates of time preference of members of the community. A rate of time preference (RTP) determined to be applicable for the community as a whole is sometimes termed a social rate of time preference (SRTP).<sup>1</sup>

The OCC and the RTP will only be the same under very restrictive conditions, including perfect capital markets, no transaction costs and no distortionary taxes

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<sup>1</sup> The term 'social rate of time preference' is sometimes used to refer specifically to rates used under a prescriptive approach. The usage here is broader, relating to any consumer discount rate deemed appropriate for the whole community.

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(Department of Finance 1991; Arnold and Sussman 1997). These conditions do not hold in practice and this tends to lead to the RTP being lower than the OCC (Cline 1992). Taxes on capital income are the main reason for the wedge between the two.

Some proposed government projects and regulations involve costs that partly displace investment and partly displace current consumption (the associated benefits may also augment both investment and consumption). This complicates the choice of discount rate because of the existence of the wedge between the OCC and the RTP. This issue has received considerable attention in the social cost–benefit literature. One suggested solution is to use a weighted average of the OCC and the SRTP, with the weights determined according to the source of funds.

Another approach is to value all resources in terms of consumption (that is, use consumption as the numeraire) and then discount using the SRTP (Arnold and Sussman 1997). Using this ‘consumption-equivalent technique’, costs and benefits that displace investment are multiplied by a shadow price of capital (that is greater than one) prior to discounting.<sup>2</sup> Explanations of this technique can be found in Lind (1982) and Cline (1992). By applying a shadow price of capital, this approach to discounting indirectly takes the OCC into account (and accordingly the effective discount rate is higher than the SRTP used).<sup>3</sup>

Australian governments often use discount rates based on the OCC in analysing proposed projects (DOFA 2006; Partnerships Victoria 2003). DOFA (2006) acknowledges that the consumption-equivalent technique is technically attractive, but points out its disadvantage in being a somewhat complex procedure. In explaining its preference for using the OCC it notes that this is a common international practice.

Reasons why governments, in general, might prefer using discount rates for policy evaluation based on the OCC, rather than applying a shadow price of capital and discounting using the SRTP, include:

- a view that the overall budget should be regarded as fixed, such that all projects can be considered to displace alternative projects and therefore have an opportunity cost of capital
- a desire to limit the overall claim on resources by the public sector
- to counter a perceived tendency for estimates of project costs and benefits not to be appropriately adjusted for downside risk

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<sup>2</sup> Under certain conditions the consumption-equivalent technique gives the same results as using the weighted average of the OCC and the SRTP.

<sup>3</sup> See Arrow et al. (1996) for a more detailed explanation.

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- simplicity (as noted above).

While many of these reasons may have validity in many cases,<sup>4</sup> they do not necessarily apply to analysing climate change. Cline (1992, p. 237) argued:

An important feature of discounting for greenhouse action is that in this area policy involves the raising of resources out of the general economy rather than the use of resources withdrawn primarily from either private investment or from alternative public-sector investments within a capital constrained budget.

Further, while the argument for simplicity has practical appeal when applied to the thousands of relatively minor proposals whose evaluation requires application of a discount rate, it seems less relevant when applied to a large-scale global issue, such as climate change.

Based on the arguments of Lind (1982), Cline (1992) used the consumption-equivalent technique to analyse climate change. Nordhaus (1994) also considers Lind (1982), but is unable to adapt the model he uses to the consumption-equivalent technique. The approach to discounting he takes is described as equivalent to Lind's, with some exceptions (Nordhaus 1994).

Like Cline, Stern takes a consumption-based approach. The analysis in the Review deals not with project costs and benefits, but with the modelling of the global economy: with and without climate change; and with and without greenhouse gas mitigation. This modelling produces estimates of consumption in each year. Accordingly, the shadow price of capital does not need to be applied explicitly, but rather the opportunity cost of any displaced investment should be taken into account within the modelling.

Lind's estimate for a SRTP that would be appropriate to use for the consumption-equivalent technique was 4.6 per cent per annum (based on the post-tax return on private assets). The very low discount rates used by Cline and Stern, therefore, are not explained by the use of this technique, but rather by them taking a prescriptive approach to deriving the SRTP, as discussed below.

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<sup>4</sup> This is not universally accepted. Arrow et al. (2005, p. 252) argue that when conducting cost-benefit analysis to evaluate environmental regulations the 'rate at which future benefits and costs should be discounted to present values will generally not equal the rate of return on private investment. The discount rate should instead be based on how individuals trade off current for future consumption'.

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## A.2 Prescriptive versus descriptive approaches

The ‘prescriptive’ approach to discounting involves taking an ethical perspective, based around asking ‘how (ethically) should impacts on future generations be valued?’ (Arrow et al 1996, p. 129). It attempts to deal with efficiency and equity issues simultaneously through the use of a social welfare function. The descriptive approach asks ‘what choices involving trade-offs across time do people actually make?’ (Arrow et al 1996, p. 129). It focuses on economic efficiency, leaving the contentious issue of equity to be considered separately.

The descriptive approach is the conventional one and it is consistent with traditional cost–benefit analysis. It is widely favoured for short and medium term analyses. However, where intergenerational considerations are important, as they are with climate change, the issue of which approach to take remains unresolved (Ackerman and Finlayson 2006; Arrow et al. 1996).

Advocates of the prescriptive approach regard market interest rates as unsatisfactory for use as discount rates in evaluating public policy. Part of the reason for this relate to the market distortions that lead the RTP to be lower than the OCC, as discussed above. Accordingly, the prescriptive approach generally utilises the consumption-equivalent technique. However, while this technique can still be *based* on market decisions (either by ‘backing out’ the distortions to arrive at a discount rate that is lower than, but still related to, the market interest rate, or empirical analysis of the discount rates underlying people’s consumption decisions), prescriptionists argue against this. This is because they believe that some features of people’s preferences imply that the SRTP will be lower than the average of individual RTPs, particularly over long timeframes. Beckerman and Hepburn (2007, pp. 203–4) list the following examples of those features:

- (i) social risk is invariably lower than individual’s risk
- (ii) many people may prefer, in their capacity as citizens, to discount the future less than they would do in making choices that affect only their personal allocation of resources ...
- (iii) at best, markets only reflect individual preferences and growth expectations over relatively short periods of time. They provide little information about people’s preferences over generations.

Advocates of the prescriptive approach often call for public debate on the ethics that should inform the selection of a discount rate and/or the use of techniques to obtain a representative estimate of social preferences. In this process, individuals proposing high discount rates, it is argued, would be making an explicit statement that they are unconcerned about the welfare of future generations.

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Those who advocate a descriptive approach do not see the issue as being resolved through a debate on ethics. Rather they think discount rates should be determined largely from a consideration of the trade-offs across time that people actually make. This tends to focus attention on market interest rates (either pre-tax or post-tax as discussed below). The main danger they see from taking a prescriptive approach is that this would produce a low discount rate, resulting in economically inferior investments being undertaken.

## Deriving discount rates

The derivation of discount rates using a prescriptive and descriptive approach is discussed below.

### *Using a prescriptive approach*

A widely used approach to deriving the discount rate using a prescriptive approach involves the use of the following equation.<sup>5</sup>

$$\text{Rate of discount} = \delta + \eta g \quad (\text{equation 1})$$

Where:  $\delta$  is the rate of pure time preference (also called the utility discount rate);  $\eta$  is the elasticity of the marginal utility of consumption; and  $g$  is the growth rate of per capita consumption. The first two,  $\delta$  and  $\eta$ , are ‘taste’ or ‘preference’ parameters, while  $g$  relates to technology (Weitzman 2007). Accordingly, there is no argument for being prescriptive about  $g$  — it should simply be forecast based on expectations (it is possible that  $g$  will be affected by climate change, however, and so there is an argument for making it endogenous to the modelling, as Stern does).

Prescriptive choices for  $\delta$  and  $\eta$  are usually based on ethical considerations. The Review sets  $\delta$  close to zero (0.1) on ethical grounds, concluding that the welfare of future generations should be treated on a par with our own. However, the choice of  $\eta = 1$  is not initially argued on ethical grounds, but rather is selected to be in line with recent empirical estimates. The ethical implication of this choice is that people derive the same utility from an additional one per cent of consumption, irrespective of their pre-existing level of consumption.

Others who advocate taking a prescriptive approach make a case for different choices. Beckerman and Hepburn argue that attaching more importance to ones children and grandchildren than to generations more distant in time, is consistent

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<sup>5</sup> This approach models the relevant social welfare function as being that for an infinitely lived individual, with a specified utility function, in a Ramsey growth equilibrium.

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with ethical theories that have ‘a distinguished pedigree going back to David Hume’ (Beckerman and Hepburn 2007, p. 198). Thus they believe that a case can be made for higher values for  $\delta$  than that used by Stern. Arrow (1995) argues that setting  $\delta$  at or close to zero demands very high savings rates and that this requires morally unacceptable sacrifices by current generations. To avoid this, his tentative conclusion is that  $\delta$  should be about 1.

Dasgupta agrees with setting  $\delta$  close to zero, but regards  $\eta = 1$  as ethically unattractive as it suggests that ‘the distribution of wellbeing among people doesn’t matter much’ (Dasgupta 2006, p. 7). He goes on to say that  $\eta = 3$  is more in line with observed data.<sup>6</sup>

As different ethical judgements are possible, a crucial question is how they should be reconciled. Stern’s suggestion is for there to be public debate:

Different people will have different value judgements. But value judgements are not arbitrary. We can, and should discuss, which of the many possible value judgements have stronger call on our attention. We can cross-question ourselves and each other and bring appropriate evidence to bear. Such exercises will not remove ethical differences of view but they can help us understand, and often narrow differences. (Stern 2007d, p. 3)

Beckerman and Hepburn (2007, p. 206) suggest that there exists a range of alternative approaches worth investigating ‘including the use of stated preference surveys, behavioural experiments, and methods to reveal the social preferences inherent in our institutions’.

In either case the aim of the process would be to arrive at choices for  $\delta$  and  $\eta$  that are, in some sense, representative of community views. It should be understood that no such process was undertaken for the Review. Accordingly, the Review’s estimates for aggregate damage costs from climate change are based on particular ethical judgements that are not, and are not claimed to be, representative of broader community views.

### *Using a descriptive approach*

Taking a descriptive approach, the focus is on choosing the discount rate so that it is consistent with the relevant market data. If it is considered necessary,  $\delta$  and  $\eta$  can then be chosen so that the right hand side of equation 1 equals this discount rate. As different combinations of  $\delta$  and  $\eta$  will achieve this objective, a choice must be

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<sup>6</sup> Beckerman and Hepburn (2007, p. 194) note ‘A striking feature of this debate is that the arguments advanced for different values of  $\eta$  are a mix of the normative [prescriptive] and descriptive’. This observation is relevant to both Stern and Dasgupta.

made, even if it is arbitrary. For example, Nordhaus appears to choose a discount rate, then set  $\eta = 1$  because it makes the modelling as simple as possible, and finally solves for  $\delta$  (Quiggin 2006).

Debate among advocates of the descriptive approach, therefore, centres on what the relevant market data are. Although somewhat dated, it is instructive to look at some of the data that Arrow et al. (1996) offered for consideration, included below in table A.1.

**Table A.1 Estimated returns on financial assets and direct investment**

<i>Asset</i>	<i>Period</i>	<i>Real return (%)</i>
<i>High-income industrial countries</i>		
Equities	1960–84	5.4
Bonds	1960–84	1.6
Non-residential capital	1975–90	15.1
Government short-term bonds	1960–90	0.3
<i>United States</i>		
Equities	1925–92	6.5
All private capital, pre-tax	1963–85	5.7
Corporate capital, post-tax	1963–85	5.7
Real estate	1960–84	5.5
Farmland	1947–84	5.5
Treasury bills	1926–86	0.3
<i>Developing countries</i>		
Primary education	various	26
Higher education	various	13

*Source:* Arrow et al. (1996, p. 133).

As table A.1 shows, some people are willing to achieve a real return of between 0 and 2 per cent per annum on low risk investments. However, returns on equities are generally much higher, often in the range of 5 to 7 per cent.<sup>7</sup>

The position taken by Nordhaus, and some other advocates of the descriptive approach, is that the discount rate should be representative of the cost of capital to the economy as a whole (Nordhaus 1994). In determining what the cost of capital to the economy is, Nordhaus argues that the returns to low yielding assets, such as government bonds, should be ignored. This is because bonds ‘represent a special and unrepresentative asset that has risk characteristics quite different from those in either conventional investment or in slowing climate change’ (Nordhaus 1994,

<sup>7</sup> Note that although average rates of return are observed, decisions are based on marginal rates of return.

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p. 129). This view leads Nordhaus to use a discount rate that starts off at around 6 per cent per annum.

Some analysts have questioned this reasoning and argued that a risk-free discount rate may be more appropriate for analysing climate change (Cline 1992; Arrow 1995). Nordhaus' argument against using a risk-free rate would seem to have generally prevailed amongst those that advocate a descriptive approach. However, Nordhaus' position has been recently challenged by Weitzman (2007).

In Weitzman's view, 'the biggest uncertainty of all in the economics of climate change is the uncertainty about which interest rate to use for discounting' (Weitzman 2007, p. 3). This uncertainty stems from two factors.

1. Uncertainty over whether climate change damages will be proportional to, or independent from, returns to the economy as a whole. Nordhaus assumes they will be proportional, but Weitzman argues that there are good reasons for thinking they will, to some extent, be independent. He cites the example of agriculture, which may be disproportionately impacted by climate change. Damages to this sector (and some others), he argues, may affect utility more or less independently of the rest of the aggregate economy.
2. The fact that the difference between empirical values of the risk-free interest rate and the return on equity are much larger than predicted by theory (the equity premium puzzle).

Weitzman argues:

... that we are genuinely uncertain about what interest rate should be used to discount costs and benefits of climate changes a century from now brings discounting rates down from conventional values [of] 6-7% to much lower values of perhaps 2-4%. (Weitzman 2007, p. 27)

Another challenge to conventional discounting has come from analysts that draw implications from the uncertainty surrounding market interest rates into the long-term future. Newell and Pizer (2001), for example, point out that few markets exist for assets with maturities exceeding 30 years, making the interest rate beyond that horizon uncertain. They show that if an uncertain random trajectory is assumed for future rates (based on historical data) the discount factor after 200 years can be many times higher than if a constant rate is assumed.<sup>8</sup>

Newell and Pizer, and Weitzman, conclude that uncertainty over the right discount rate to use for the distant future is a reason for using lower discount rates (and

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<sup>8</sup> Costs and benefits in future years are multiplied by a discount factor that is less than one in order to convert them to present values. The higher the discount rate, the more steeply the discount factor declines. (The discount rate is the rate of decline of the discount factor.)



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therefore higher discount factors) than if there was no uncertainty. This is perhaps counterintuitive as one might think that the uncertainties cancel each other out and that an average rate should be used. The reason this is not the case relates to the exponential effects of discounting — it is discount factors and not discount rates that need to be averaged (for a full explanation see Newell and Pizer 2001).

For example, say there is uncertainty about whether to use a 3 or 8 per cent discount rate and that each is equally likely to be correct. A dollar received in one year's time is either worth  $\$1/1.03 = \$0.97$  or  $\$1/1.08 = \$0.93$ . The average is  $\$0.95 (=1/1.054)$ , which implies a discount rate of 5.4 percent, close to the average of 3 and 8. But a dollar received in 100 years' time would be worth  $\$0.05 (= \$1/(1.03)^{100})$  with a discount rate of 3 percent and  $\$0.0005 (= \$1/(1.08)^{100})$  at 8 percent, which averages to  $\$0.03 (= \$1/(1.037)^{100})$ . The implied discount rate is 3.7 percent, much closer to 3 than to 8 percent. That is, if we are uncertain about which discount rate to use, the appropriate discount rate declines over time.

As has been shown, a wide range of discount rates have been suggested as being appropriate under a descriptive approach.

## **Critiquing the two approaches**

As might be expected, advocates of each approach generally regard the other approach as deficient. The reasons given for this are discussed below.

### *Critique of the prescriptive approach*

The prescriptive approach to discounting has been criticised for a range of reasons, including the following.

#### *Being likely to lead to inferior investments being undertaken*

Those that advocate a descriptive approach to discounting point out that, regardless of the source of funds, undertaking an investment involves the use of scarce resources that could have been used for other purposes. Given that the prescriptive approach typically leads to low discount rates, it is argued that this will lead to the selection of inferior investments. For example, undertaking low-yielding climate-related investments at a time when some potentially high-yielding investments in education and health in developing countries are not being funded.

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### *Requiring unreasonable levels of savings by current generations*

It has also been argued that low discount rates imply that current generations should save an unreasonably high proportion of income (Dasgupta 2006; Weitzman 2007). Weitzman, in discussing thought experiments based on Stern's discounting parameters, concludes:

For me (and I suspect most economists) sensible savings rates ... require the rate of pure time preference to be significantly greater than zero (or at least if  $\delta$  is chosen to be relatively small then  $\eta$  should be chosen to be relatively big). (Weitzman 2007, p. 8)

### *Not being representative of community preferences*

The prescriptive approach is often seen as attempting to impose the ethical views of the analyst on a community that does not share those views. As has been discussed above, the prescriptive approach does not necessarily have to be applied in an unrepresentative way. However, the fact that it often is (including by Stern) gives legitimacy to this criticism.

### *Mixing efficiency and equity issues when they are better addressed separately*

Unlike in traditional cost–benefit analysis, the prescriptive approach attempts to address efficiency and equity issues together. Economic efficiency has an explicit positive meaning and it can be estimated using economic techniques. Assessing equity, on the other hand, requires value judgements to be made — individual philosophers, economists and others have their own views, but these can differ significantly. Mixing the two concepts in cost–benefit analysis can prevent insights into efficiency from being gained and give a false sense of objectivity to the results.

Some descriptionists argue that concerns over equity can be legitimate, but that they are best considered separately, rather than through adjusting the discount rate (Goulder and Stavins 2005). For example, if a cost–benefit analysis suggested that only modest levels of greenhouse gas mitigation were efficient in the near term, it could still be debated whether more should be done on intergenerational equity grounds.

### *Being likely to be ineffectual in ameliorating perceived intergenerational inequity*

Taking a prescriptive approach to discounting can promote the adoption of public projects that have a net cost to current generations and produce benefits for future generations. Warr and Wright (1981), however, have shown that it can not be taken for granted that implementing such projects will result in overall improvements for future generations. This is because current generations may respond to these

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government actions by reducing their private efforts (for example bequests) at improving the welfare of future generations.

### *Critique of the descriptive approach*

The concept of potential Pareto improvement underlies the descriptive approach. To see this, consider a case where the discount rate reflects the opportunity cost of capital and a proposed policy for climate change mitigation fails the cost-benefit test. The reason it fails is that the winners from inaction (current generations) would, potentially, be able to invest an amount slightly less than the cost of mitigation that could be used to fully compensate the losers (future generations).

The advocates of the prescriptive approach argue against the descriptive approach on the grounds that potential Pareto improvement is an unsuitable criteria where policy creates winners and losers between generations. Beckerman and Hepburn (2007, p. 189) articulate this case:

It is generally accepted that although actual compensation is necessary, in principle, to ensure that any move is Pareto-optimising, this is invariably impossible in practice (and perhaps in theory as well), so that one must fall back on one or other of two defences of the [potential Pareto improvement criteria]. The first is that in a large society with lots of projects carried out, it can be assumed that losers on some projects are likely to be gainers on others. The second defence is that, anyway, the socially desired distribution of income in any democratic society is in the hands of the government and if, for one reason or another (including a bias in the projects selected), it is desirable to change the distribution, this can always be done via appropriate taxes and benefits.

However, these defences are not available for climate change, where policy creates winners and losers between generations and intergenerational compensation is not possible. First, future generations that may benefit from any current policies cannot compensate those today who may bear the costs of the policy. Second, the swings and roundabouts argument cannot apply intergenerationally. Losers in the present generation have no hope of being winners in any subsequent generation. Thirdly, there is not, and can never be, any inter-temporal government that can adjust the intergenerational income distribution in accordance with any trans-generational views on what would be an equitable intergenerational distribution of welfare.

Adopting a descriptive approach can be seen as answering the question: Is investment in climate change mitigation expected to produce higher returns than those available elsewhere in the economy? To those who advocate a prescriptive approach, this is the wrong question as investments in mitigation do not necessarily displace other investment. Instead they prefer to ask: Is investment in climate change mitigation expected to be welfare enhancing? Answering this question, it is argued, requires the use of a social welfare function constructed from ethical considerations, rather than the potential Pareto improvement criteria.

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