Institute of Actuaries of Australia

The Economics of Climate Change – the Stern Review

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Presented to the Institute of Actuaries of Australia
Biennial Convention 23-26 September 2007
Christchurch, New Zealand

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The Economics of Climate Change
The Stern Review

Abstract

Keywords: *climate change, economic models, cost benefit analysis*

This paper describes the analysis that has been completed by the Stern Review in assessing the long term global economic impacts (over more than 200 years) of climate change if no action is taken to reduce greenhouse gas emissions and, alternatively, the net economic benefits of strategies to reduce emissions.

There is general agreement about the Review's recommendation of the immediate implementation of strategies to stabilise greenhouse gas emissions in order to limit the possibility of temperature increases in the next century of more than 3 degree C. Increases above this level are likely to lead to major detrimental and irreversible changes to the Earth's climate systems.

However critical comments have been made by several academics about the Review's assumptions together with their implications for the speed of action to reduce emissions. These criticisms are described and discussed in the paper. Many of the issues raised in relation to discount rates and inter-generational and intra-generational equity will be of interest to actuaries. Members are invited to contribute to the debate.

Introduction

Mains supply of electricity was developed late in the 19th century and motor vehicles became commonplace in the following couple of decades. One hundred years ago, who would have imagined the dramatic changes that would occur to human lives as a result of these developments?

No doubt if these changes had been predicted, they would have been welcomed by most people. But now we are facing a predicament because of their unintended consequences. The increasing levels of worldwide emissions of greenhouse gases from the combustion of fossil fuels used by these new technologies and the progressive accumulation of these gases in the Earth's atmosphere are leading to deleterious changes in climate.

The reversal of this trend is a major challenge. Modelling by scientists of the Earth's climate systems indicates that it will take more than one hundred years to reverse the processes that are causing these changes and return the climate systems to "normal stability".

These days the development of government policy is dominated by the consideration of impacts on the economy. Policies are designed to generate economic growth (increases in average incomes) and, in theory, improve overall wellbeing.

Governments have recognised that action has to be taken to reduce greenhouse gas emissions in order to mitigate the risk of serious consequences arising from climate change. However they are worried about the economic consequences of this action. To date most widely publicised analysis has focused on the economic costs of reducing greenhouse gas emissions and, until recently, little attention has been paid to the costs of not taking action.

Sir Nicholas Stern, a former chief economist of the World Bank, was commissioned in 2006 by the Chancellor of the Exchequer to report to the UK government on the economics of climate change in the UK and globally. The report, titled the Stern Review on the Economics of Climate Change (the Review), was published in October 2006. The Stern Review is therefore viewed as a groundbreaking report because it addresses the costs of inaction explicitly, but also its scope goes considerably further.

Brief from the UK Government

The terms of reference for the Review are copied in Appendix 1. In particular the Review was asked to provide:

- An assessment of the economics of moving to a low-carbon global economy, focusing on the medium to long-term perspective, and drawing implications for the timescales for action, and choice of policies and institutions.

- An assessment of the potential of different approaches for adaptation to changes in the climate.

Contents of this paper

This paper will focus on the economic assessments made in the Review of the potential impacts of climate change and policy strategies to reduce the level and risks of climate change. It does not cover the later chapters that go into detail on adaptation, policy development and implementation. These subjects will be covered by other papers presented to the Convention.

The paper is divided into the following sections:

Appendices:

See the **Glossary** for more detailed information on the terminology used in this paper.

Most of the material in this paper has been drawn from the Stern Review report and other materials on the Review website (www.sternreview.org.uk). The website includes several research papers and reports that were commissioned as part of the Review.

Acknowledgements

I am very appreciative of the assistance I have received in writing this paper from Fred Rowley, in particular, in developing some understanding of utility theory as used by the Review. Also I have received assistance from members of the Energy & Environment Committee and Professor Dodo Thampapallai from Macquarie University.

1. Scope of the Economic Analysis

In the most comprehensive analysis to date of the issue[1], the Review considers the economic costs of the impacts of climate change and the costs and benefits of action to reduce the emissions of greenhouse gases (GHGs) that cause it, in three different ways

- Using **disaggregated techniques** or bottom up approaches to describe the physical impacts of climate change on the economy, on human life and the environment of the various regions of the world.

- Using **economic models,** principally Integrated Assessment Models, that estimate the global economic impacts and risks of climate change and macroeconomic models that represent the costs and effects of the transition to low carbon energy systems.

- Comparing over time the **social cost** of the impacts of an additional unit of emission of GHG against the marginal abatement cost. This provides a guide to policymakers for the microeconomics of policy development and timing of implementation of emissions reduction strategies.

The methods used have had to take into account the following features of the climate change issue which make the parameters of the analysis very different to those of the usual economic analysis.

1. The impact of the emissions is global and independent of the location of the emitter;

2. The environmental and economic impacts on different parts of the world will vary for geographic and socio-economic reasons;

3. There is a likelihood that the economic changes will be radical rather than marginal;

4. The momentum of climate change that is already in the climate systems from past emission levels;

5. The exceedingly long timeframes that will be involved before the level of greenhouse gases in the atmosphere and the global climate can be stabilised;

6. There are considerable uncertainties about the potential size, timing and nature of the impacts and hence uncertainties about their costs;

7. The uncertainty of the effectiveness of policy decisions and infrastructure implementation in reducing GHG emissions;

8. The potential risks of increased incidence of catastrophes;

9. The potential risks that irreversible changes will occur, including radical changes and dynamic feedbacks in the Earth's climate systems.

[1] The results of previous models are described in the Review. The principal models were developed by RO Mendelson, R Tol and W Nordhaus during the 1990s. Details are provided in the paper Warren et al, 2006 available from the Stern Review website. They do not cover the full range of impacts or possible temperature increases covered by the Review.

Period Covered by the Analysis

The relationship between GHG emissions occurring at one point in time and their impact on climate and the economy involves several time lags:

- Emissions remain in the atmosphere for many years, CO_2 for about 100 years. So emissions now are contributing to the concentration in the atmosphere as far away as 100 years time.

- It will take several years to implement the changes in the technology and infrastructure of energy production and consumption patterns that will reduce levels of emissions.

- The action of the natural carbon absorption systems (such as oceans) is related to global temperatures. It is believed that the absorption process may be compromised at higher temperatures leading to an amplification of the temperature increase.

- The inertia in the climate system leads to a delay in the response to changes in concentrations. If the concentration is stabilised at a particular point in time, the global temperature would continue to increase for another 100 years and sea level rises would continue for several centuries (IPCC 2001).

All these factors lead to the need to carry out the analysis over a period of at least 200 years.

Methodology

The analysis has to encompass the aspects of risk, uncertainty, equity within and between generations and allocation over time. The analysis of mitigation options has to consider that, in future, the technologies available to produce energy with lower emissions is likely to become cheaper. However the longer the delay in implementing these technologies, the greater the reduction in emissions that will be required or the greater the risk that effective reductions that will control the level of climate change will not be achieved.

Therefore, the important economic assumptions are:

- Discounting philosophy and rates
- Projected costs of mitigation
- Future income (or social welfare) valuation
- Future valuation of various damage functions, such as the representation of extreme events
- Treatment of risk and uncertainty
- Treatment of adaptation.

The basic concepts to be applied in the analysis are drawn from the theory of welfare economics. This approach analyses the consequences of a development or policy in terms of the impact it will have over time on the consumption of goods and services and therefore the well-being of the community. In addition to marketable goods and services, the goods and services can include items of intrinsic value such as education, health and environmental quality which are also potential indirect inputs into the use and acquisition of other consumption goods (for example productivity of labour and land use). Individuals gain “welfare” or “utility” from this consumption and the overall objective of the policy development is to increase or maximise this.

The Review focuses on the implications of action and inaction on climate change for the 4 dimensions of consumption, education, health and environment within and across generations with an explicit allowance for risk. However, how these dimensions are assessed will vary according to the ethical position taken. The quantitative assessment needs to aggregate consequences of different kinds for different people. This needs to consider how to allow for the welfare of people with very different standards of living. For example, developing countries will be particularly badly affected because of their geographic location, dependence on agriculture and fewer resources to adapt to climate change.

The tool usually used to evaluate national policy is cost benefit analysis (CBA). Many of the methods used in the Review draw on the principles of this approach. However a broad interpretation of these principles has been adopted because of the features of the climate change issue; principally the long timeframe, the international coverage, the need to account for non-marginal changes and considerations of intergenerational equity.

Throughout the Review there is acknowledgement of the difficulties and inadequacies of the economic analysis that is being undertaken. Emphasis is made of the need for judgments to be made of the results taking into account qualitative information and ethical perspectives.

The approaches and assumptions used have led to a great deal of discussion and criticism which will be outlined in this paper.

2. Overview of the climate change scenarios analysed

This paper will not go into the detail of the science of climate change or the forecasts of its physical impacts on the Earth's ecosystems. A brief overview is provided in order to provide an understanding of the reasons for the approaches taken in the economic analysis.

Throughout this paper references are made to carbon dioxide equivalent (CO_2e) emissions. This covers all gases whose presence in the atmosphere has an influence on the greenhouse effect such as carbon dioxide and methane. See the Glossary for more details.

The level of CO_2 in the atmosphere prior to the industrial revolution was 280 ppm.[2] The current level of CO_2 is 380 ppm. When other greenhouse gases that have an effect on global warming, such as methane, are added the current concentration is equivalent to a CO_2 concentration (CO_2e) of 425 ppm. Annual emissions were around 42 Gt CO_2e (in 2000) leading to an increase in concentration by about 2 to 2.5 ppm CO_2e per year.

At current emission levels the GHG concentration is predicted to rise to 550 ppm by 2050. This commits the world to ultimate warming of between 2 to 5 deg C[3] (see Table 2.1 below). This level of warming is far outside the experience of human civilisation. But emissions are still increasing so that, if no action is taken (the business as usual or BAU scenario), the projections made by the Intergovernmental Panel on Climate Change (IPCC) indicate that the concentration could increase to 650 - 1200 ppm by 2100 depending on which scenario is applied for future economic development and population growth (see Glossary for more details on these scenarios).

Table 2.1 below summarises the predicted range of increases in temperature related to the possible CO_2e concentrations levels[4] at stabilisation. Current temperatures are believed to be 0.7 deg C above pre-industrial levels already.

Table 2.1: Temperature increase predictions

Stabilisation Level (ppm CO_2-e)	Temperature increase at equilibrium relative to pre-industrial (deg C), 5 – 95% ranges	
	Hadley Centre[5]	IPCC TAR 2001
450	1.7 – 3.7	1.0 –3 1
500	2.0 – 4.5	1.3 - 3.8
550	2.4 – 5.3	1.5 – 4.4
650	2.9 – 6.6	1.8 – 5.5
750	3.4 – 7.7	2.2 – 6.4
1,000	4.4 – 9.9	2.8 – 8.3

[2] Emissions of other greenhouse gases were not significant at this time.
[3] Levels of climate change are usually defined in terms in increases in global temperatures but the actual consequences of any change vary for each geographical zone in terms of their impact on temperatures, water availability, sea level change and occurrences of extreme weather events. These changes can be harmful or beneficial (at lower temperature increases).
[4] These figures are quoted from the IPCC Third Assessment Report and the Hadley Centre (UK's official centre for climate change research). These two studies are the ones usually referred to in the Review. There are many other studies referred to in the Review with wider uncertainty ranges and generally higher central estimates. Temperature increases are relative to pre-industrial levels.
[5] Study published in 2004 by Murphy et al,.

Business as usual predictions

The Review has adopted the scenario from the IPCC known as A2 as the basis for projections under BAU. Under A2 the predicted concentration of GHGs in the atmosphere by 2100 is 1,250 ppm CO_2e. The eventual increase is not stabilised at 2100. Under the A2 scenario, the predicted temperature increase by 2200 is expected to be 3 to 10 deg C, a wide range.

These climate change predictions are used by the Stern Review for what is termed their "Baseline" case. The predicted mean temperature by 2100 is an increase of 3.9 deg C relative to pre-industrial levels with 90% confidence range of 2.4 to 5.8 deg C. The increase quoted here is lower than the range quoted in Table 2.1 but the temperature change has not stabilised by 2100.

The Review also incorporates another scenario which adds allowance for another set of impacts that have not been previously modelled. These are the additional effects that could arise if major changes occur to climate systems leading to amplifying feedback effects. Examples of the types of changes that have been predicted are the weakening of carbon sinks or melting of permafrost leading to an acceleration of GHG emissions. There is data available from the scientific studies that allows for probabilities to be attached to these events. The addition of these feedbacks raise the mean temperature increase at 2100 by 0.4 deg C from 3.9 deg to 4.3 deg C and the 90% confidence interval to 2.6 to 6.5 deg C. This is referred to as the "High Climate" case.

By 2200 the mean increase is 7.4 deg C under the Baseline case and 8.6 deg C under the High Climate case. The Review emphasises that these figures are only indicative as the climate models available mostly do not go beyond 2100.

Appendix 2 shows a graphic of impacts of the various temperature increase levels.

Criteria for setting mitigation goals

Many studies have been made of the trajectories of GHG emission levels, the predicted concentrations in the atmosphere and the possible ranges of the resulting temperature increases over time. The graph below from the CSIRO paper (Preston and Jones 2006), commissioned by the Business Roundtable on Climate Change, provides a comprehensive illustration of the risk ranges of temperatures increases for various stabilisation levels. Please note that this graph covers the stabilisation of CO_2 only. When other gases are included the horizontal axis needs to be shifted left by about 80 ppm.

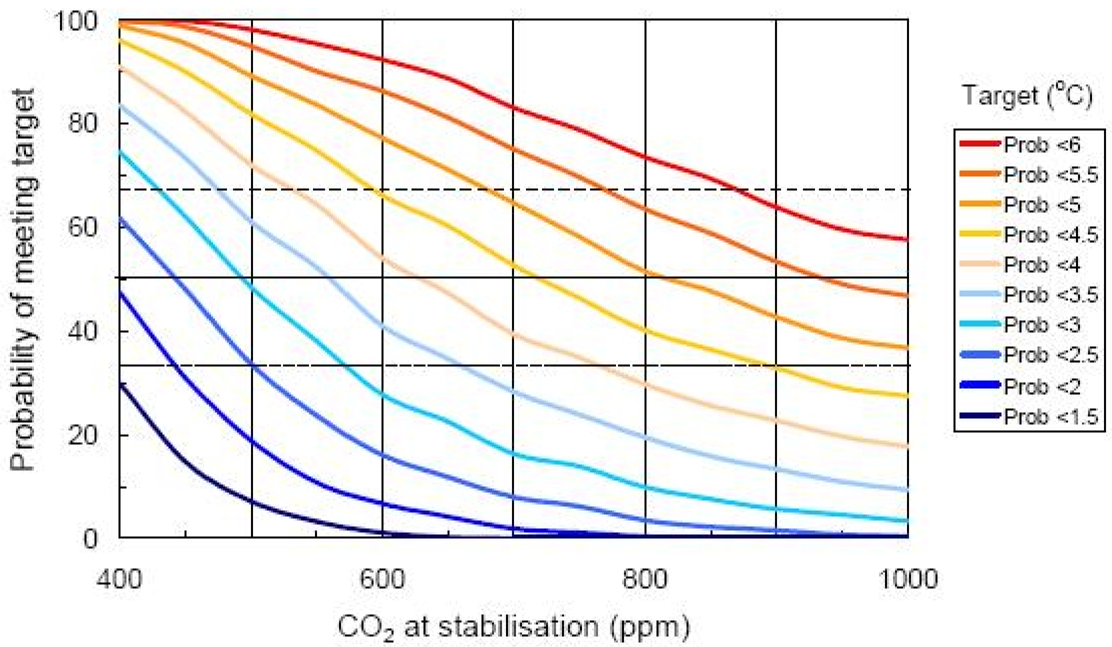


Figure 6. *Probabilities (expressed as a percent) of remaining below a range of targets for global mean temperature change (at the time of stabilisation) given different atmospheric CO_2 stabilisation levels and assuming a climate sensitivity range of 1.5-4.5°C.*

The Review argues that a temperature increase of more than 3 deg C above pre-industrial levels is highly undesirable because of the severe impacts predicted to occur. Using the results of the IPCC and Hadley Centre studies, the Review nominates 550 ppm CO_2e as the goal for the maximum stabilisation level. At this level there would still be a 30-70% chance of a temperature increase above 3 deg C and a 10-24% chance that temperatures would increase above 4 deg C and, even a 10% chance that the increase would be above 5 deg C. These probabilities of increases over 3 deg C still appear high but, as explained in the next section, a lower stabilisation level could be too costly or technically difficult to achieve.

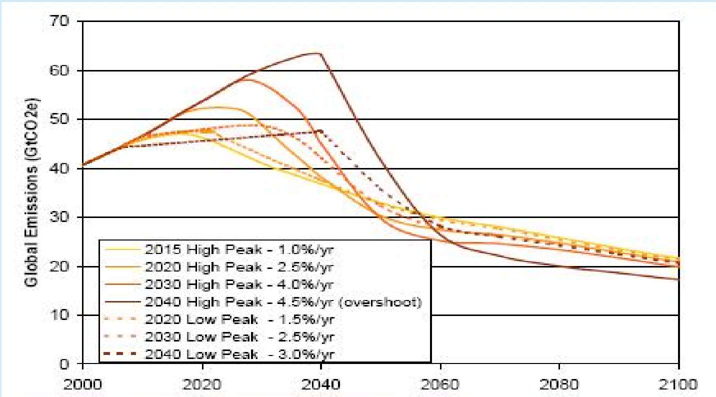
The minimum feasible stabilisation level, given the current concentration, is 450 ppm CO_2e. At this level there is a high chance of staying below 4 deg C.

Setting the stabilisation objective

The Review discusses various studies that have been made of the costs of implementing some mitigation objectives and finds that there have been no satisfactory studies completed to date. It is suggested that economic analysis will help in the setting of a range of goals. As explained above, the Review considers increases in temperatures of more than 3 degrees to be undesirable. This corresponds to an ultimate concentration level of no more than 550 ppm CO_2e. It then considers the feasibility of achieving stabilisation at this level. The possible paths of future emission reductions that would achieve this goal are shown in Figure 8.2 from the Review below.

Figure 8.2 Illustrative emissions paths to stabilise at 550 ppm CO_2e.

The figure below shows six illustrative paths to stabilisation at 550 ppm CO_2e. The rates of emissions cuts are given in the legend and are the *maximum* 10-year average rate (see Table 8.2). The figure shows that delaying emissions cuts (shifting the peak to the right) means that emissions must be reduced more rapidly to achieve the same stabilisation goal. The rate of emissions cuts is also very sensitive to the height of the peak. For example, if emissions peak at 48 $GtCO_2$ rather than 52 $GtCO_2$ in 2020, the rate of cuts is reduced from 2.5%/yr to 1.5%/yr.



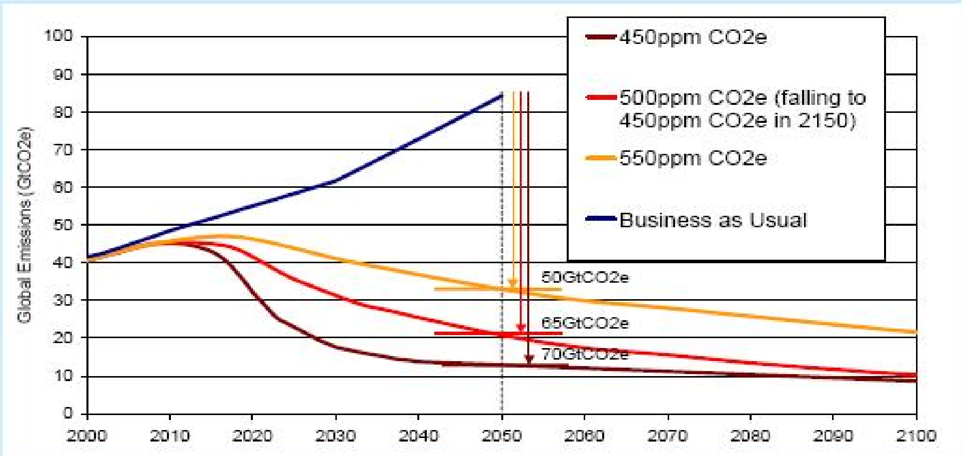
Source: Generated with the SIMCaP EQW model (Meinshausen et al. 2006)

The graph demonstrates that emissions would need to peak in the next 10 to 20 years and then fall by around 1 – 3% per year if stabilisation is to be feasible. It also demonstrates the importance of early action. For example, the Review considers that it will be difficult to achieve a reduction of more than 3% per year. Therefore a delay in the starting point for the reduction in total emissions beyond 2020 will jeopardise the ability of achieving stabilisation at 550 ppm.

The impact of climate change will still be significant if stabilisation at 550 ppm is achieved. However the Review considers that more stringent goals will be too costly even if they were feasible within the foreseeable future. Figure 8.4 from the Review shows the required reductions in annual emissions levels relative to expected levels under BAU.

Figure 8.4 BAU emissions and stabilisation trajectories for 450 - 550 ppm CO_2e

The figure below shows illustrative pathways to stabilise greenhouse gas levels between 450 ppm and 550 ppm CO_2e. The blue line shows a business as usual (BAU) trajectory. The size of the mitigation gap is demonstrated for 2050. To stabilise at 450 ppm CO_2e (without overshooting) emissions must be more than 85% below BAU by 2050. Stabilisation at 550 ppm CO_2e would require emissions to be reduced by 60 – 65% below BAU. Table 8.2 gives the reductions relative to 2005 levels.



Ultimately the annual GHG emissions must reduce to the level that the Earth systems can absorb, which the Review says is 5 $GtCO_2e$. The current level is about 40 Gt so the level will have to be reduced to about 80% of current levels. The reduction relative to possible BAU emissions levels is much greater. The statement is made that "*As reducing emissions in agriculture appears relatively difficult, and that sector accounts for more than 5Gt CO_2e per year by itself already, stabilisation is likely ultimately (well beyond 2050) to require complete decarbonisation of all other activities and some net sequestration of carbon from the atmosphere*".

3. Overview of modelling and results

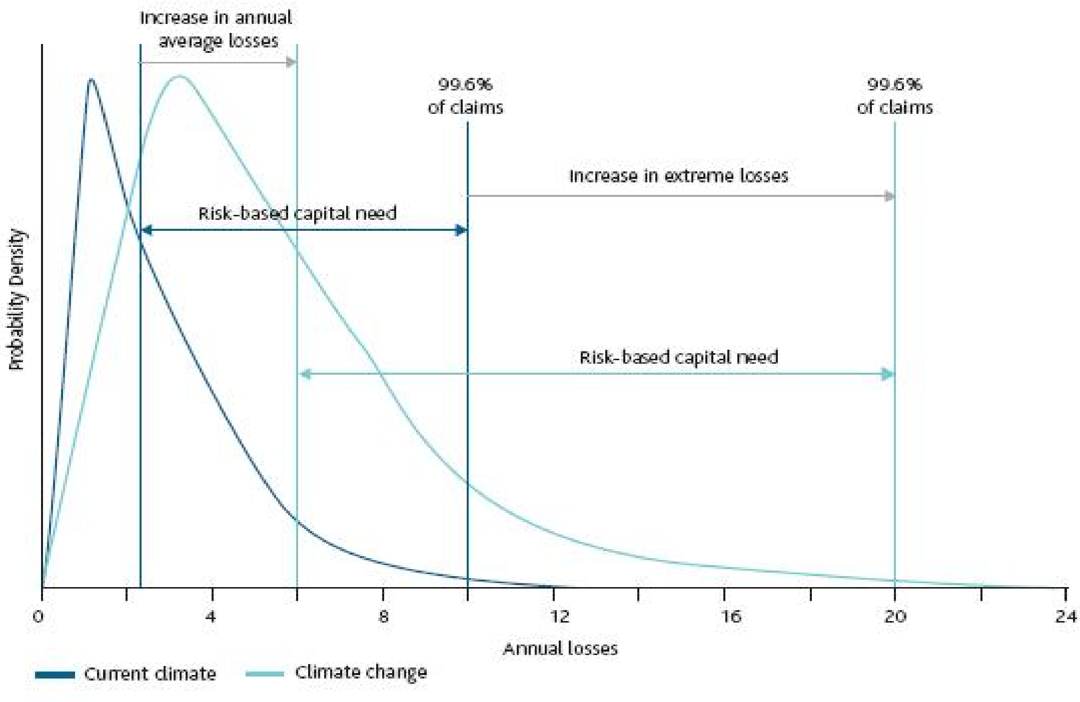
A. Disaggregated techniques

The Review devotes many pages to descriptions of the economic and social effects of climate change on agriculture, health, extreme weather events in each region of the world. Much emphasis is placed on these potential outcomes because of the difficulties of quantifying these impacts from an economic point of view. When it comes to considering major dislocations of populations or changes to ecosystems, economic analysis does not provide a means of assessment. Ethical judgement is required to define the point where the risk of these unquantifiable projected changes should be avoided if at all possible.

For developed countries, the most significant impacts of climate change are likely to arise from extreme events in the required replacement of infrastructure and losses of production. Losses in world GDP from extreme events have averaged 0.2% in the 1990s (Hurricane Katrina cost about 1.2% of US GDP) and could reach 0.5 – 1% of world GDP by the middle of this century. At higher temperatures, the convexity of the damage function could lead to costs increasing sharply to several percent of world GDP.[6]

Of particular interest to actuaries is the section copied below that illustrates the effect that the increase in extreme weather could have on insurance capital requirements.[7]

Figure 9.1 Impact of climate change on probability loss distribution and implications for risk capital requirements



If storm intensity (measured by windspeed) increases by 6%, as predicted by several climate models for a rise in temperature of 3˚C, this could increase insurers' capital requirements by over 90% for cover over US hurricanes and 80% for Japanese typhoons.

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[6] For example, hurricane damages scale as the cube of windspeed (or more), which itself increases exponentially with ocean temperatures.

[7] Source, Association of British Insurers: Financial Risks of climate change, June 2005 summary report, available from www.abi.org.uk/flooding

B. Integrated assessment models

The assessment of the global economic impact of climate change is made using an Integrated Assessment model (IAM) which simulates the process of climate change from the emissions of GHGs through to the socio-economic impacts.

The measure of impacts to be used is the difference in "income" that is expected to occur with and without climate change.

GDP, the value of economic output, is generally used as the measure of income. However GDP is measured in national accounts as economic output and will include expenditures required in response to climate change such as storm defences. In the Review, income or consumption is used in order to estimate an allowance for the removal of these "non-productive" expenditures.

The IAM covers market sectors such as energy and agriculture for which market prices are readily available. Non-market impacts are also allowed for but no details are provided in the Stern Report on how this is done. This raises the challenge of expressing health, mortality, environment quality, etc in terms of income. Often, willingness to pay is used as a measure of these impacts. But the willingness to pay is dependent on the ability to pay, for example an increase in mortality would affect income more in a wealthy country than a poor country. However no detail is provided on how this allowance is made.

In addition there are risks that are a familiar situation today such as catastrophes that occur infrequently but have major consequences. Catastrophe risks are allowed for using data from studies such as the one by W Nordhaus (2006) on future costs of US hurricanes[8]. An example of the impact of this risk is that extreme events are expected to reduce world GDP by 0.5% to 1% pa by 2050 and continue to increase with higher temperatures in the longer term.

Core assumptions

The core assumptions used before any allowance is made for the effects of climate change are:

- Average GDP per capita growth rate of 1.3% pa.
- Average worldwide population growth rate 0.6% pa.
- Rate of saving (netted off income to convert into consumption) 20%[9]
- Beyond 2200, it is assumed that growth will continue at a rate of 1.3% pa but with no further population growth and no further change in climate.

These assumptions are consistent with the IPCC A2 scenario (see Glossary).

[8] http://nordhaus.econ.yale.edu/hurr_122106a.pdf).

[9] This appears to be applied as a constant assumption, but one would think savings rates would be affected by income levels. This tendency may be mitigated by the varying level of enforced demand for investment in 'defensive' capital projects.

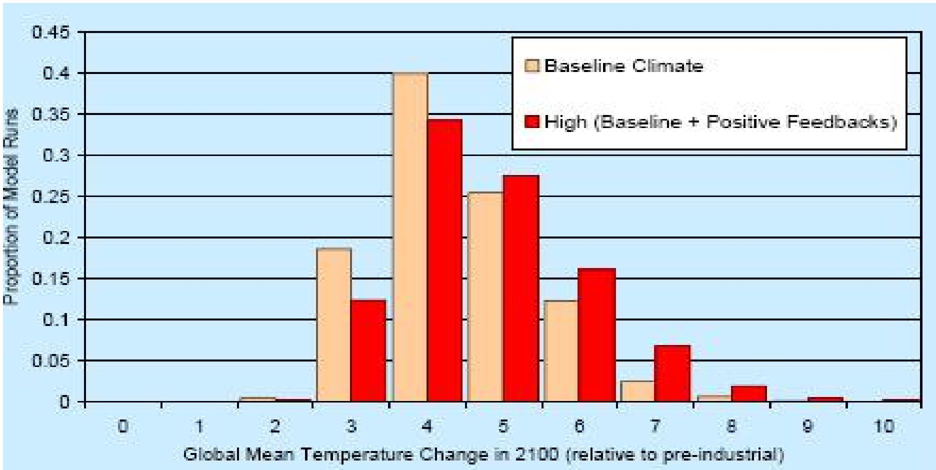
Allowance for uncertainty

The Review has to allow for uncertainties in relation to

- Future rates of economic growth and the associated volume of emissions
- Increases in temperature arising from the level of emissions
- The impact of the temperature rises
- The economic cost of policy measures, that is, the cost of reducing emissions

The major innovation with the Stern Review compared with other IAMs is the explicit allowance made for uncertainty. This is done by applying a stochastic process adopted by a model known as PAGE2002 (Policy Analysis of the Greenhouse Effect 2002) developed by Professor Chris Hope from the University of Cambridge. 1,000 simulations are run applying a set of parameters each chosen randomly from a predetermined range of possible values derived from several scientific studies. The studies predict the possible temperatures and climate changes that will occur in response to the level of GHGs in the atmosphere, which are generated by the level of economic growth built into the model. These climate change occurrences then, in turn, have an impact on economic growth, incomes and the cost of adaptation. A comparison is then made of these levels of incomes against the baseline income growth projection.

The chart below shows the distribution of temperature changes predicted to occur by 2100 under the BAU projection under the Baseline and High Climate cases.



Appendix 2 shows graphs of the losses in GDP per capita over time for the various scenarios[10]. These graphs highlight the losses of incomes expected from the allowances for:

- Market impacts and risk of catastrophes;
- Non-market impacts; and
- The addition of the High-climate scenario.

[10] The GDP figures are converted to income at a later stage.

Evaluation over time

Having generated a series of probability distributions of future income loss, the Review then had to find a way to aggregate all this information into an overall assessment of global welfare costs of climate change. The evaluation over time should apply some means of comparing incomes over time on a common basis. It is predicted that economic growth will continue so that incomes many years from now will be considerably higher than they are now.

The usual practice of welfare economics in project and policy appraisal is to consider that a change in future consumption (or utility) is worth less than an increment in present consumption because:

- People will be better off in the future because of economic growth.
- There is a preference for consumption now over future consumption, usually referred to as the pure rate of time preference or utility discount rate.

The model allows for economic growth but the present value of the projected incomes uses a low utility discount rate of 0.1% pa. This is discussed in more detail in section 4.

The projected values of utility from the consumption paths derived from these 1,000 runs of the model are added together and averaged. This present value is compared with the present value of the utilities from consumption based on a fixed level of growth (business as usual without climate change). The starting level of consumption is scaled up or down in order to match the value of the BAU consumption path with the average of the climate change affected paths, called a Balanced Growth Equivalent. The cost of climate change is defined as the difference between the total value of income without climate change and the Balanced Growth Equivalent with climate change. The Review describes this difference as the permanent loss of consumption "*now and forever*" or it can be thought of as "*a tax levied on consumption now and forever, the proceeds of which are simply poured away.*"

Costs of adaptation

With all parts of the analysis it is necessary to allow for the costs of adaptation, for example the construction of sea walls, development of new plant varieties, new water supply infrastructure. It cannot cancel out the costs of climate change and still has to occur even when mitigation has been applied. However a reduction in the costs of adaptation is one of the benefits of mitigation.

Examples of the allowances applied are that adaptation reduces the impact on market sectors (such as agriculture) in developed countries by 90% at all levels of warming and 50% in lower-income countries, relative to changes without adaptation. Non-market impacts (eg human health and natural ecosystems) are reduced by 25% worldwide.

Cost of Climate Change under Business as Usual

The results of the modelling are summarised in Table 3.1 below.

Table 3.1 - Losses in current per-capita consumption				
Scenario		**Balanced growth equivalents (BGEs): projected average % loss in current consumption due to climate change**		
Climate	**Economic**	**Mean**	**5th Percentile**	**95th Percentile**
Baseline	Market impacts	2.1	0.3	5.9
	Market + catastrophe risks	5.0	0.6	12.3
	Market + catastrophe + non-market impacts	10.9	2.2	27.4
High climate	Market impacts	2.5	0.3	7.5
	Market + catastrophe risks	6.9	0.9	16.5
	Market + catastrophe + non-market impacts	14.4	2.7	32.6

The Review warns against over-literal interpretation of these figures but "*they illustrate … the risks involved in a 'business as usual' approach to climate change are very large.*"

Intra-generational adjustments

The figures Table 3.1 provide an overall assessment of the loss of total world income. However, the total incomes in the developed countries are much higher than for the developing countries so the results are weighted towards the results for richer countries. Developing countries have a high proportion of the world's population. They will bear a more significant burden from climate change because of their geographical locations and lesser ability to adapt to climate change. The Stern Review did not carry out any detailed assessments using alternative methods that would have given greater weight to the impacts on developing countries. A possible method is to calculate the income impacts on a regional level and then to aggregate the results using weighting based on population rather than income. Other studies that have used this method, for example by (Nordhaus and Boyer, 2000 and Tol, 2002) have led to increases in the assessed loss of GDP by 25% to 100%.

Costs of mitigation

The analysis of mitigation options has to consider that in future the technologies available to produce energy with lower emissions is likely to become cheaper. However the longer the delay in implementing these technologies, the greater the reduction in emissions that will be required or the greater the risk that reductions sufficient to control the level of climate change will not be achieved.

The Review commissioned a meta-analysis of model simulations. This came to the conclusion that the average cost over the period to 2100 of policies to stabilise GHGs at 550 ppm would be 1% of gross world product. By 2050 the plausible range of costs is from –2% (net gains) to + 5% of GDP. There will, of course, be variations between countries and industry sectors.

The method of costing used is not affected by the discounting assumption and is designed to be consistent with the Balanced Growth Equivalent method used for the costing of damages described above.

Critics argue that these cost predictions are overly optimistic. In a follow up paper (Dietz et al, 2007) the costs are defended as robust to reasonable changes in assumptions. The costings are, however, based on assumptions of sound policy and early action. The chief policy requirements are:

1. Full pricing of the emissions via taxes, trading schemes or regulation (to provide adequate stimulus for mitigation and adaptation).

2. Public funding to support development and application of low carbon technologies (and thus ensure adequate capabilities and levels of supply).

3. Behavioural change measures to improve take up of less carbon-intensive consumption of goods and services (including the individual consumer and government as well as corporate entities, and going well beyond simple pricing).

Costs of climate change with stabilisation

Appendix 5 shows 2 graphs which compare the difference in global product between the BAU scenario and the situation with emissions stabilised at 550 ppm CO_2e after allowing for mitigation costs at an average level of 1% of GWP or, alternatively, 4% of GWP. The Review does not explain in detail how these graphs have been constructed. There is a statement that the graphs do not allow fully for catastrophes and non-market impacts.

Earlier in this Section it was shown that the predicted cost of climate change under BAU is around 11% of consumption now and forever under the baseline scenario. The Review did similar analyses under the assumption that the concentration of GHGs in the atmosphere will be stabilised at 550 ppm. This reduced the loss to 1.1% of consumption "now and forever". Choosing a tougher goal of 450 ppm would reduce the loss to 0.6%, and alternatively choosing a slightly weaker goal of 650 ppm increases losses by about 0.6%.

The conclusion can be drawn that a cost of about 1% of GDP for the implementation of mitigation measures will reduce the impact of climate change from the BAU cost of 11% to about 1% of consumption "now and forever".

C. Social costs of extra emissions versus marginal abatement cost – a price based approach

As a separate exercise to the assessment of the cost of climate change, the Review has made some calculations of the social cost of carbon (SCC). SCC is the impact at a point in time of emitting an extra unit of carbon (or its equivalent) on the present value of expected utility or welfare (or consumption). The concept has theoretical difficulties in definition and quantification because the results are dependent on the predicted path of future emissions. The size of the impact (the damage cost) also depends the assumptions made about the lifetime of the gas, the existing stock of GHG in the atmosphere, how uncertain impacts of climate change are valued and discounted and expressed in terms of a numeraire such as consumption.

The purpose of developing this calculation is to:

1. Convey the fundamental message that every tonne of GHG emitted imposes a measurable cost on society.

2. Demonstrate the net economic benefits of mitigation, by allowing a comparison with the marginal abatement cost (MAC). This comparison might be used to validate a minimum price for emissions permits (and/or the emissions fee) as an input and/or support to government emissions policy. However, market prices themselves would develop from the quantitative goals (including especially caps and emissions fee levels) that are set on policy grounds, allowing for other considerations such as political risk. As such, they may not be sufficiently strong early in the operation of the proposed trading scheme. This leads to a second use of the comparison.

3. Demonstrate continuously (for as long as the social cost at any time is higher than the cost of abatement) that it is economically positive to invest in abatement. This may be extended to include a continuing implication that a responsible government can be expected to continue to drive up emissions prices (through its operation of the cap reviews and setting of the fees etc.) until the price (and actual mitigation costs) meet the SCC.

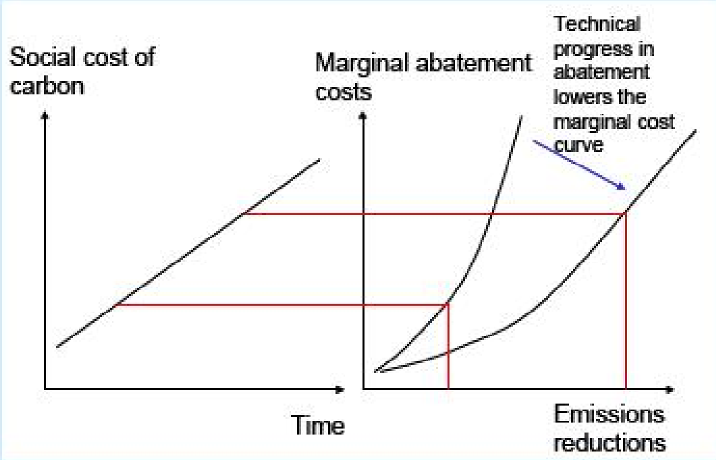
In summary, the aim of the exercise is to send signals to the market to support emissions pricing policy and validate actual market prices at a level that is realistic in achieving the desired degree of abatement, as well as indicating a likely future progression of that price.

However there are practical difficulties in this idea. For example, if there are differences between the discount rates used to determine the SCC and the implied discount rate being used by the current market then the incentives may not work as intended.

Measuring and comparing the expected benefits and costs over time associated with different stabilisation levels can provide guidance to help decide how much to do and how quickly.
It is very likely that the SCC will rise over time because the stocks of GHGs will rise as further emissions take place until the stage is reached when the concentration of GHGs in the atmosphere is stabilised. The MAC is also assumed to increase over time because abatement will be harder as the mitigation objective becomes tougher. A dynamic optimisation process will be involved in matching the SCC and MAC as is described in Box 13.1 from the Review below.

The increase in the SCC over time will be faster the higher the expected impacts rise with concentrations and the higher the discount rate. This last point has been the major source of controversy over the results of the Review. The assumptions used the Review led to a higher initial level of the SCC than would be expected to increase at a slower rate over time than calculation using a higher discount rate. This implies encouragement for greater early action than other studies as discussed further in Section 4.

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



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

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

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

The PAGE2002 model points to a SCC[11] under BAU of \$US 85/tCO_2e using the baseline sensitivity assumption including allowance for non-market impacts and catastrophe risk. By comparison, along a trajectory to a stabilisation of 550 ppm CO_2e the SCC would be \$US 30/tCO_2e and along a trajectory to 450 ppm would be \$US 25/tCO_2e.

[11] Often the cost of carbon emissions is quoted rather than the cost of CO_2 emissions. The conversion factor is based on atomic weights. 100 tonnes CO_2 is equivalent to 27 tonnes of carbon – see Glossary.

The Review also explains that the SCC can be used to calculate an estimate of the benefits of climate change policy, as follows:

The gross benefits of policy for a particular year = $(SCC_H \times E_H) - (SCC_S \times E_S)$

The annual cost of abatement = SCCs x $(E_H - E_S)$

Benefits less costs = $(SCC_H - SCC_S) \times E_H$

where:

SCC_H is the social cost of carbon under high emissions pathway
SCC_S is the SCC under a stabilisation pathway
E_H is the emissions in one year with high emission
E_S is the emissions in one year with stabilisation

Based on the information in this section, the net present value of a targeted climate change policy for one year could be of the order of $2.3 trillion [($85-$25) x 40Gt$CO_2$e] allowing for current emissions of 40 GtCO_2e.

In the subsequent paper (Dietz et al, 2007), the Review members state that, on a path to stabilisation at 550 ppm, the benefit of abating one tonne of CO_2 (the avoided damages and adaptation costs) is higher that the cost of abatement. But, on a path to stabilisation below 450 ppm, the incremental cost of abatement is likely to be higher than the benefits.

4. Discussion of assumptions and ethical arguments

The criticism of the Review has been concentrated in 2 areas, the scientific projections and the assumptions used in the economic modelling. In subsequent papers (including allowance for results for the 2007 IPCC Assessment Report), Stern has defended vigorously the climate change and mitigation cost predictions as being sound and, if anything, on the conservative side of the overall range of predictions produced by the full range of studies that have been made (Dietz et al, 2007). This paper will not describe these arguments.

The following paragraphs outline the opinions that have been expressed about the methodology and assumptions used in the economic modelling. Firstly, the background theory for economic analysis on a country or global scale is described.

Theoretical approach to economic appraisal

A theoretical approach for the appraisal of issues that involve trade-offs between costs now and benefits in the future, has already been developed for the appraisal of significant projects at a national level. Its applications are not always comparable in concept with climate change, although the fundamental approach has been adapted for use in the Review. The method used for this appraisal is called cost benefit analysis (CBA).

Many of the criticisms of the Review have been made from the perspective of the principles of traditional CBA.

Stern argues that CBA is inappropriate for climate change policy because:

1. CBA examines efficiency and ignores equity. Projects that are economically efficient but disadvantage some members of society are justified on the grounds that there will be a system in place to redistribute income to achieve equity. However there is no intergenerational system to redistribute wealth. Although economic instruments such as taxes could be used, there is no mechanism available to make the required allocations to the disadvantaged generation (or country within that generation). In other words, the equity allowances implied in CBA are inadequate and explicit consideration is required.

2. The welfare economics framework normally underlying CBA is inadequate as it does not address questions of rights and responsibilities owed to future generations

3. CBA is not appropriate for non-marginal policy problem. CBA is only applicable for marginal perturbations around a predicted path where a positive net present value can guarantee an increase in social welfare. It may have been appropriate for the level of intervention that has been undertaken so far. But with climate change, a significant reduction in GDP is predicted, for example, the scenarios that result in a significant reduction in GDP (eg 35.2% at 95th percentile) have a disproportionate effect on welfare calculations because they reduce income to levels where every marginal dollar of income has greater value. The merit of a non-marginal policy intervention needs to be assessed by comparing the stream of social welfare (or utility) with and without intervention.

Discounting (from Hepburn, 2006)

For marginal developments that are being evaluated using methods such as CBA, it is often convenient to think about the trade off between the utility of present and future consumption in terms of a shadow discount rate. This is a means of converting costs and benefits (in terms of utility and constant prices) at different times into common units at a present date. The discount rate depends on the level of future consumption which, in turn, depends on the level of productivity and economic growth rates.

Shadow discount factors normally fall with increasing time because people prefer to have good things earlier rather than later and capital tends to yield positive returns – we expect to be better off in the future than we are today.

The shadow discount factor is given by $D(t) = 1/ (1 + s(t))^t$

The discount rate, s, is given by

$$s(t) = \delta + \eta * g(t)$$

where

δ is the utility (or wellbeing) discount rate or pure rate of time preference; and
η is the elasticity of marginal utility of consumption
$g(t)$ is the real rate of growth of consumption.

If climate change impacts are expected to slow down economic growth or lead to recession then the social discount rate should decline accordingly. Economic growth refers to the growth in the value of goods and services provided by the economy, including non-market sectors. This leads to the question (which could be discussed at length) of how economic growth is measured. The conventional measure is growth in GDP but this inadequately measures non-market sectors.

Assumption used for the utility discount rate

The Review has adopted a time preference rate of 0.1% pa. This is designed to represent the chance of extinction. No allowance is made for pure time preference.

Assumption used for the elasticity of the marginal utility of consumption

The assumption adopted for the elasticity of marginal utility of consumption is 1. This measures how fast the value of an increment in consumption falls as consumption rises. With η equal to 1, an extra unit to A with 3 times the consumption of B would have one-third the value it would have for B. If η is equal to 2, the extra unit would have approximately one-ninth the value. A high η means a higher preference for current income, high aversion to risk and larger benefits from redistribution.

The assumption covers the allowance for variations in incomes between present and future generations. As explained in section 4B, the Review refers to the use of equity weighting to allow for variations in income levels of the present generation. For future generations, it is argued by the critics that the use of an elasticity of 1 implies a low level of aversion to variations in future incomes relative to current incomes. The inclusion of so many considerations in one parameter makes for complicated discussion of the assumptions. This will be covered in more detail below.

The core assumption for the rate of growth of income per capita is on average, over 200 years, 1.3% pa combined with a population growth rate of 0.6% pa. There is variation assumed between countries or regions and over time, for example the growth rate (real GDP plus population growth) commences at 2% pa for developed countries and 4% pa for Asia.

However the growth rate assumption varies in the longer term in response to the impact of the climate changes predicted under each stochastic scenario as it is run through the model.

Discussion of the assumptions

During the development of the international process that led to the Kyoto Protocol during the 1990s there was much analysis and discussion by academics and policymakers about the economics of global warming and, in particular, the issue of discounting. Several books and journal papers were published on the subject. Commentators included several Nobel Prize winners, such as Kenneth Arrow and Thomas Schelling.

The response to the Review indicates that little progress has been made over the past two decades in developing a framework for climate change policy. Many of the arguments discussed in the book edited by Tietenberg (1997) are still being hotly debated in the response to the Stern Review. Many of the discussions of the assumptions used in the Stern Review are highly technical. I will try to provide a broad overview.

For a low discount rate

In one of the papers written for the Review, Cameron Hepburn from the University of Oxford argues the case against using market rates such as the real risk free market rate:

- market prices often give a misleading signal of value because of other distortions in the economy such as taxation and externalities;

- markets only reveal the preferences of the current generation and do not cover the long periods relevant to climate change analysis.

He states that time preference represents the desire for individuals to consume now or impatience. The consumer is concerned with their *own* consumption but greenhouse policy is about someone else's future consumption. It is also a question of how citizens of a society would act rather than how individuals would act. The climate change analysis is more about comparing our generation's income relative to future generations. T Schelling (1995) makes the same argument.

As argued by Brad DeLong (2006): "*Investments in controlling global warming are not risk-increasing but risk-reducing ones; they are more like buying insurance than like speculating on unproven technologies*".

In other long term investment appraisals where discounting is used, such as large infrastructure, pure time discounting can reflect the risk of the investment becoming redundant, for example a railway that loses custom because of cheap air fares. This is not relevant to the climate change issue.

Against a low discount rate

Birdsall and Steer (1995) from the World Bank argue that the low discount rate for investments in environmental protection is often defended on the grounds of uncertainty and irreversibility but this is an imperfect and misleading tool. More appropriate valuation techniques for the environmental costs should be used instead. The monetary value placed on climate change should use the same rate as will be applied to new projects being considered in response to the issue.

Schelling (1995) argues that if GDP per capita continues to increase before abatement costs become significant, then marginal utilities will be much higher in the next 50 years than in the following 50 years. This factor tilts the advantage towards direct investment in the development that can raise living standards in the next 2 generations (reducing dependence on climate susceptible economic activities) compared with investment in climate stabilisation.

Nordhaus (2007a) and Lind (1995) also argue that the discount rate should be consistent with the rate sanctioned by UK Treasury guidelines for CBA which is in line with the risk free real rate of return.

On balance the majority of contributors consider that little or no allowance should be made for time preference.

The Review states that the allowance of 0.1% pa is intended to cover the risk of extinction. One wonders what difference it would make if there were no allowance for pure time preference? In fact, the equations used to calculate the total welfare with and without climate change "*now and forever*" will not converge unless the discount rate is greater than zero.

Robert C Lind (1995) considers that CBA cannot provide a definitive basis for deciding whether to commit to climate change mitigation. Under the principles of CBA, if future generations are going to be much better off financially, then there should be a mechanism for future generations to compensate current and near term generations to their investments in emission reductions. However, the issue of inter-generational equity is not about changes in GWP but the possibility of irreversible and catastrophic effects from climate change.

Elasticity of marginal utility

A related criticism of the low discount rate is the criticism of the adoption of a low value of elasticity of marginal utility. Nordhaus (2007b) provides the following arguments against the use of η equal to 1:

- This parameter represents the aversion to economic inequality among different generations; a low value implies that little notice is taken that future generations might be much richer.
- Society will therefore save a great deal for the future and the real return will be low.
- The damage costs in the distant future (more than 200 years) overwhelm the results of the Stern analysis[12]
- If an elasticity of 3 is used, the real returns implied will be much closer to actual market data and the figures for the social cost of carbon and climate change damages will be much closer to the result from other models.
- These current models point to a much lower carbon tax and therefore to a slower implementation of carbon abatement measures.

[12] As pointed out by Yohe (2006), more than 50% of the calculation relates to damages beyond 2200. If a higher discount rate is used, the damages beyond 2200 could reduce to about 20% (with 1% assumption for the pure rate of time preference) and even lower at higher assumptions.

A corollary of this argument is that current policy should provide for greater redistribution of current incomes towards poor countries so that they may develop the capacity to respond and adapt to the consequences of climate change in the future.

In a similar vein, Maddison (2007) argues that it might be cheaper at the margin to compensate victims of climate change than to abate GHG emissions. I question whether money can compensate for irreversible damages such as sea level rises or loss of the Great Barrier Reef.

In response to the arguments for the use of a higher overall social return on investment through either a higher η or δ, Dietz et al (2007) questions whether we should be confident that returns could be similar to the past experience of 3% or 4% pa in private real returns on capital into the long term future if there is the possibility of strong climate change externalities.

Other comments and criticisms

Table 4.1 below summarises the other major points of disagreement with the assumptions and results and the response made by the Review members, mostly in the paper by Dreiz et al (2007).

4.1 Summary of Points of Criticism

Criticism	Sources	Response from the Stern Review members
Central estimate of mitigation of 1% of GDP is too low	Tol and Yohe (2006)	1% of GDP per year is not trivial – in the middle of the range of respected modelling studies. Level of cost is dependent on a flexible and clear global policy framework.
Methods of costing mitigation (over 50 years) are not consistent with the costing of damages.	Yohe (2006)	Don't agree
Applying the economic theory of the relationships between growth rates and savings rates, the assumptions used by the Stern Review imply impossibly high savings rates.	Dasgupta (2006), Maddison (2006), Arrow (1995) and Nordhaus (2006)	The analysis they are applying does not allow sufficiently for technological improvement.
Other ways of spending money have higher social rates of return so strong action to address climate change should occur later.	Bjorn Lomborg (2006) (Copenhagen Consensus)	Doesn't take account of the severe risks of high temperatures and increases in costs of stabilisation if action is delayed.
The IPCC SRES scenario chosen overstates likely future growth	Byatt et al, 2006	The rate of population growth might be too high relative to productivity growth – see sensitivity testing results. But the growth in emissions implied in the BAU assumptions is consistent with other projections, such as by the Int'l Energy Agency.
Science is out of date	Byatt et al, 2006	A comprehensive review was made of recent literature and the science used has been confirmed by the 4th IPCC Report released in 2007.
Risk is overstated by use of biased assumptions	Tol and Yohe, 2006, Byatt et al, 2006	Don't agree, if anything the studies that form the basis for the stochastic analysis are conservative. No allowance has been made for socially contingent impacts such as conflict and migration.
Inadequate allowance for adaptation	Byatt et al, 2006	Don't agree. Significant allowance is made (see description in Section 3).

The most strident critics, such as Tol and Yohe (2006) and Byatt et al (2006) claim that the alarmism and dubious economics may further polarise the climate policy debate. It will allow opponents of early action to focus on estimation errors and away from the important message. Dietz et al (2007) dismiss their assertions on the grounds that their analysis is confused

On the other hand, economists who have been leaders in the field (eg Dasgupta and Nordhaus), despite their criticisms of the Review, all conclude that ethical arguments are paramount in supporting the urgency for action to reduce global warming.

Examples of sensitivity testing varying assumptions

In response to the critics of the approaches taken in the Review, results of sensitivity testing have been published in various papers, for example in the review Postscript, Dietz et al (2207) and Hamid et al (2007).

The results of the sensitivity testing described in the subsequent papers published on the Stern Review website is somewhat bewildering as here are so many variables being considered and, as demonstrated in Table 3.1 above, there is such a broad range of results within the 5 to 95 percentile range. Some examples of the results are shown in Table 4.2 below covering only the effect on in the average result of the change in assumption.

4.2 Results of sensitivity testing

Variation	Central case	Sensitivity	Change in mean total cost of BAU climate change (percentage points)
Base assumptions			***10.9% BGE***
Pure time preference rate	0.1% pa	1.5% pa 1.0% pa	-7.8% -5.9%
Elasticity of marginal utility of consumption	1	2 3	-7.5% -9.8%
Allowance for risk and uncertainty	Stochastic valuation	“Best guess” mode value	-7.6%
Damage function exponent (see Glossary)	Mode = 1.3, max = 3	Mode = 2.25, max = 3	+23.3%
Catastrophic changes	With allowance	No allowance	-2.9%
Equity (population) weighting instead of income weighting	No allowance	With allowance	+6%
Output growth	200 year average 1.3% pa	Increase by 1%	Small increase
Population growth	21.5 bill by 2200	40% reduction of population at 2200, but same emissions	-4%
High climate assumptions			***14.4% BGE***
Pure time preference rate	0.1% pa	1.5% pa 1.0% pa	-10.5% -8.0%
Elasticity of marginal utility of consumption	1	2 3	-7.3% -1.5%[13]

[13] The reduction is smaller than under the baseline case because, with η= 3, risk aversion begins to overtake the effects of using a higher effective social discount rate

5. Conclusions

So what has the Review contributed to the understanding of the climate change issue? Are the criticisms going to lead to a lack of credibility or further procrastination? Does the Review make a constructive contribution to the process of developing responses to the climate change issue?

There have been some forthright criticisms published in the environmental economics journals, particularly *World Economics*, and in weblogs, describing the Review's findings as alarmist and failing to provide a sound foundation for policy development (in particular Nordhaus and Maddison). However, despite these criticisms, many of the authors conclude that urgent action is required to reduce emissions, simply for ethical reasons that the consequences are so significant that action has to be taken.

Once the science has been accepted, the ethical arguments become paramount and this has implications that modify traditional CBA approaches that have for formed the basis of the criticisms of the Review's methods, in particular the discount rate.

As stated in the Stern Review report, "*In many ways, the science has progressed further than the economics".* Therefore much more work is required to develop a framework for the development of policies to respond to the scientific, technological, social and economic issues inherent in the climate change issue. As there is a high degree of uncertainty we should position ourselves to respond effectively to future events by developing a sequential decision making system (a control cycle) that can be fine-tuned as further information becomes available.

There are strong ethical reasons to start acting now despite the uncertainties and the potential for future advancement of technologies. Interesting parallels can be drawn between the climate change issue and the human genome project. A Richard Dawkins (2003) states in one of his essays: "*Given the rate of technological advances, with hindsight, when we started the Human Genome Project it wasn't worth starting. It would have been better to do nothing until the last two years and start then! The fallacy of the "never bother to start' maxim is that later technologies cannot get into a position to 'overtake' without the experience gained in developing earlier ones."*

The Review emphasises that "*Some of the uncertainties will be resolved by continuing progress in the science of climate change, but ethical and social values will always have a crucial part to play in decision-making. The choice of policy objective will depend on values, attitudes to risk and judgements about the political feasibility of the objective"*

The actuarial perspective could add helpful insights to the issue. The Review has demonstrated that it is not possible to quantify the costs of action and inaction in any simplified manner suitable for the two minute item on the television news. There is a need to select particular aspects of the issue, especially those aspects where equity is a consideration, and provide information that highlights the risks in ways that can be interpreted and responded to by decision makers.

For adaptation, information will be needed to:

- identify high risk areas for physical or economic consequences (eg flood plains, bushfire prone areas, future non-viable agricultural areas)

- create a risk profile under the range of possible climate change effects

- define the appropriate response strategy (eg insurance, economic assistance, shifting population, change in infrastructure)

6. Setting goals for climate change policy

Throughout the Review there is emphasis placed on the shortcomings of the methods and results of the analysis. These shortcomings relate to the:

- uncertainty of the scientific projections
- uncertainty of the effectiveness of the response
- uncertainty of the assumptions

The Review is a work in progress. One of the main objectives is to provide a foundation for concerted action in reducing emissions and adapting to climate change.

The Review includes some discussion of the best way forward in defining the objectives for future strategy for reducing emissions. The objectives should be:

- Related to impacts trying to avoid
- Easy to monitor
- Provide a proactive means of adjusting policy

The Review suggests five possible types of objective that are summarised below together with their advantages and disadvantages.

Type of objective	**Advantages**	**Disadvantages**
Maximum tolerable level of impacts *(Similar to UNFCCC goal)*	• Linked directly to consequences	• scientific, economic and ethical difficulties in defining tolerance levels • Uncertain means of linking impact to be avoided with human action • Can only measure success retrospectively
Global mean warming above a baseline *(Definition used by EU)*	• Can be linked to impacts • Simple variable to quantify	• Uncertain means of linking impact to be avoided with human action • time lags between human action and temperature changes so hard to relate objective to actions
Concentration of GHG	• One quantifiable variable • Can be linked to human action (with some uncertainty) • Can be measured quickly	• Uncertainty about magnitude of avoided impacts
Cumulative emissions of GHGs over a given time period	• One quantifiable variable • Directly linked to human action • Can be measured quickly	• Uncertainty about magnitude of avoided impacts
Reduction in annual emissions by a specific date	• One quantifiable variable • Directly linked to human action • Can be measured quickly	• Uncertainty about magnitude of avoided impacts • Does not address problem directly as impacts are a function of stocks not flows • May limit flexibility of timing and so push up costs

The more indirect methods seem in general to heighten the risk that the world might be inadvertently locked into a higher-than-optimal emissions pathway.

An alternative approach could be to have two frameworks for setting policies based on shorter and longer term considerations.

The long term goal could be defined in terms of a precautionary approach of based on the absolute maximum acceptable concentration of GHGs in the atmosphere. The goal would be set based primarily on scientific understanding of the risks of:

- extreme weather events
- dynamic feedbacks
- irreversible changes in the Earth's systems
- other risk aversion criteria.

The shorter term goals would cover the period required to stabilise the absolute level of emissions and move down to the level that the Earth's systems can absorb, say the next fifty years. These goals would be based on a combination of science, technical feasibility and economics. However the longer term goal would still have to act as a ceiling over the shorter goal considerations.

7. Implications for Australia's response to climate change

In Australia, analysis of the climate change issue has focussed on the costs of reducing emissions. The major long term study by Allen Consulting (2006) was commissioned by the Business Roundtable on Climate Change. This study's conclusions were similar to those of the Stern Review that the cost of reducing emissions by 60% below 2000 levels by 2050 would be of the order of 1% of Australia's GDP.

The only study in Australia of the long term impacts of climate change if effective action is not taken to reduce emissions and the costs and benefits of policy intervention has been commissioned by the Federal Labor Party and state and territory governments. This review, the Garnaut Review, is due to distribute a draft report for comment by 30 June 2008 and publish its final report by 30 September 2008. The terms of reference are copied in Appendix 5.

The Garnaut Review will be faced with similar problems to those of the Stern Review in finding ways of explaining the impacts of climate change that will inform debate on the best response options. In addition to the problems highlighted in the Review of the global risks and uncertainties in the climate change impacts, technological development and effectiveness of policy responses, there will different considerations for the Garnaut Review. Some of these will make the task easier.

Examples are:

1. The climate impacts are easier to define for a smaller geographical area. However, Australia has a notoriously variable climate so development of economically efficient adaptation strategies will be tricky. For example, will some agricultural areas need to be supported with increased irrigation infrastructure or will it be more economically efficient to abandon them?

2. Australia will have a moral obligation to reduce emissions in the same way as will be required by other countries with similar levels of development.

3. Future economic development will be affected by the worldwide impacts of climate change in areas such as the cost of importing food, population movements and the need for capital reserves to support increased risks that may or may not be insured.

It is expected that Members of the Institute of Actuaries will have the opportunity to make submissions to the Garnaut Review.

The major problem with debate thus far on the response to the climate change issue in Australia has been the focus on short term impacts on some sectors of the economy. The Business Roundtable has demonstrated that the impact on the overall economy of reducing emissions is not likely to be significant. Discussion of the issues raised in this paper should assist in informing the development of ideas of practical ways of defining action strategies.

Appendix 1

Terms of Reference

The terms of reference of the review are to:

Examine the evidence on:

- The implications for energy demand and emissions of the prospects for economic growth over the coming decades, including the composition and energy intensity of growth in developed and developing countries;

- The economic, social and environmental consequences of climate change in both developed and developing countries, taking into account the risks of increased climate volatility and major irreversible impacts, and the climatic interaction with other air pollutants, as well as possible actions to adapt to the changing climate and the costs associated with them;

- The costs and benefits of actions to reduce the net global balance of greenhouse gas emissions from energy use and other sources, including the role of land-use changes and forestry, taking into account the potential impact of technological advances on future costs; and

- The impact and effectiveness of national and international policies and arrangements in reducing net emissions in a cost-effective way and promoting a dynamic, equitable and sustainable global economy, including distributional effects and impacts on incentives for investment in cleaner technologies

Consult with key stakeholders, internationally and domestically, to understand views and inform analysis.

Based on this evidence, provide:

- An assessment of the economics of moving to a low-carbon global economy, focusing on the medium to long-term perspective, and drawing implications for the timescales for action, and choice of policies and institutions.

- An assessment of the potential of different approaches for adaptation to changes in the climate.

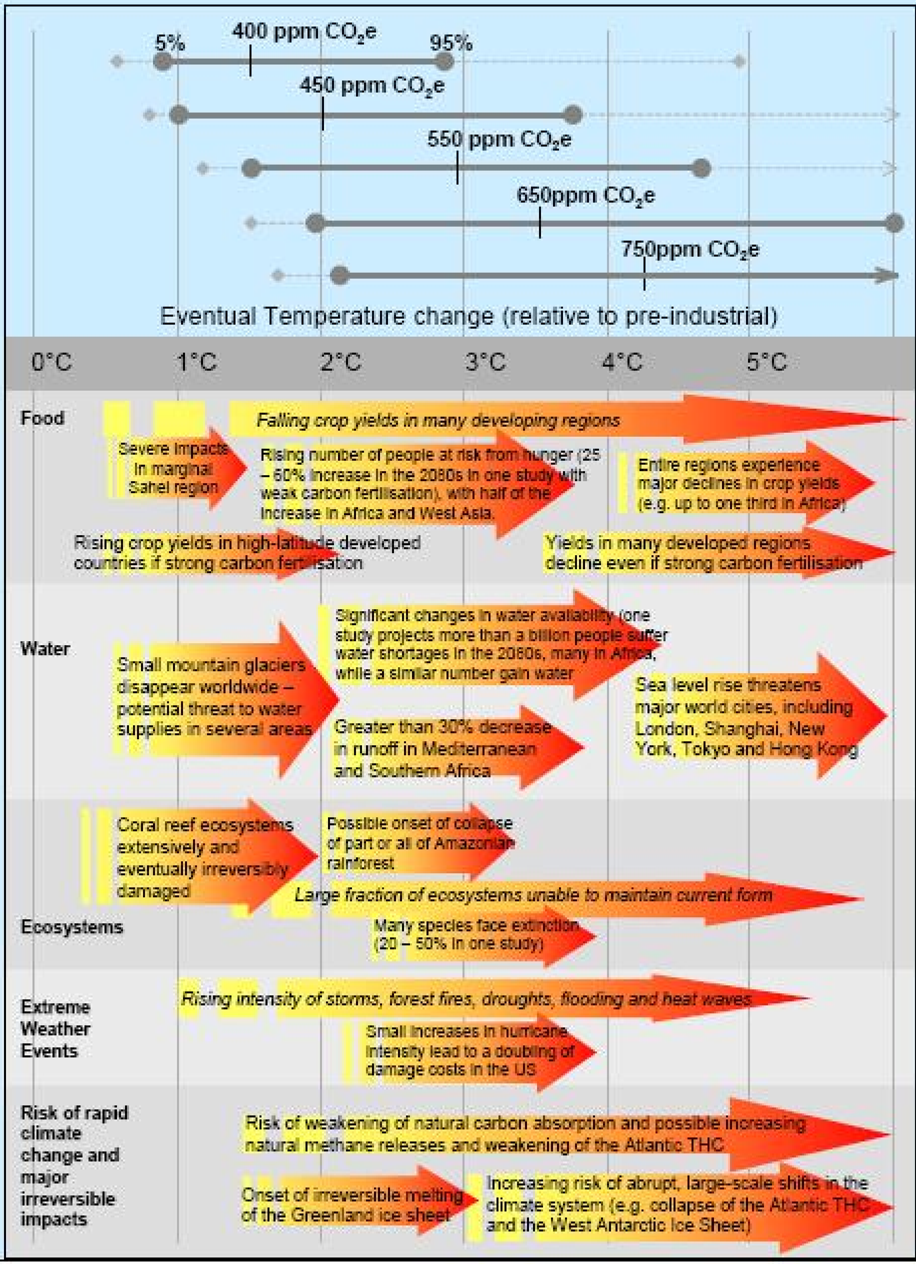
Assess how this analysis applies to the specific case of the UK, in the context of its existing climate change goals.

Produce a report to the Prime Minister and Chancellor by Autumn 2006.

Appendix 2

Figure 2 Stabilisation levels and probability ranges for temperature increases

The figure below illustrates the types of impacts that could be experienced as the world comes into equilibrium with more greenhouse gases. The top panel shows the range of temperatures projected at stabilisation levels between 400ppm and 750ppm CO_2e at equilibrium. The solid horizontal lines indicate the 5 - 95% range based on climate sensitivity estimates from the IPCC 2001[2] and a recent Hadley Centre ensemble study[3]. The vertical line indicates the mean of the 50^{th} percentile point. The dashed lines show the 5 - 95% range based on eleven recent studies[4]. The bottom panel illustrates the range of impacts expected at different levels of warming. The relationship between global average temperature changes and regional climate changes is very uncertain, especially with regard to changes in precipitation (see Box 4.2). This figure shows potential changes based on current scientific literature.



Appendix 3

Figure 6.5 a. Baseline-climate scenario, with market impacts and the risk of catastrophe.

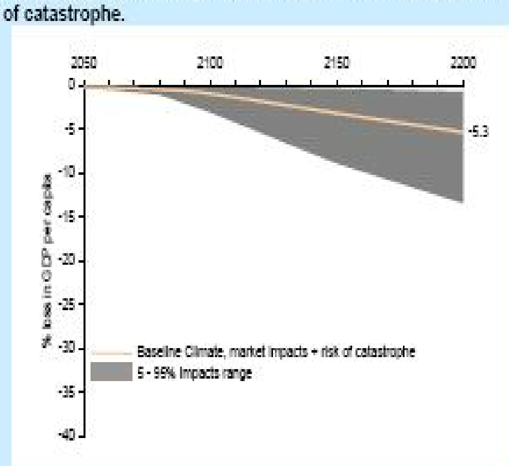


Figure 6.5b. High-climate scenario, with market impacts and the risk of catastrophe.

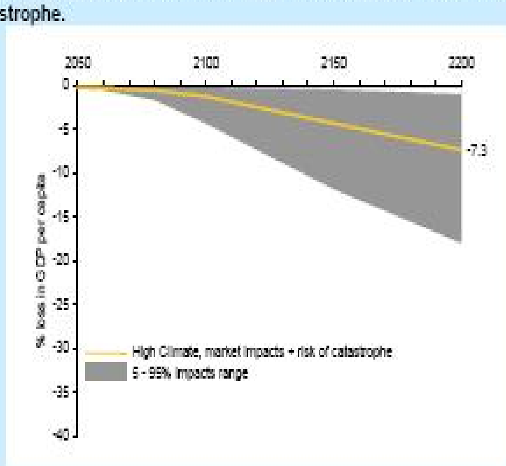


Figure 6.5c. High-climate scenario, with market impacts, the risk of catastrophe and non-market impacts.

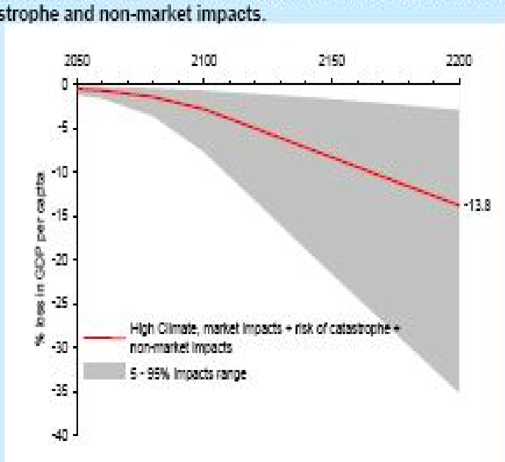


Figure 6.5d. Combined scenarios.

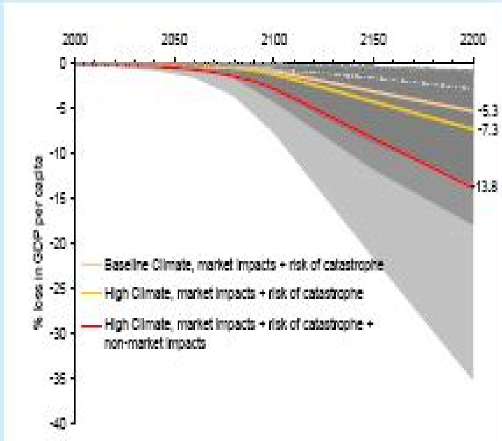


Figure 6.5a-d traces losses in income per capita due to climate change over the next 200 years, according to three of our main scenarios of climate change and economic impacts. The mean loss is shown in a colour matching the scenarios of Figure 6.4. The range of estimates from the 5th to the 95th percentile is shaded grey.

Appendix 4

Figure 13.1 'Output gap' between the '550ppm CO_2e and 1% GWP mitigation cost' scenario and BAU scenario, mean and 5th – 95th percentile range

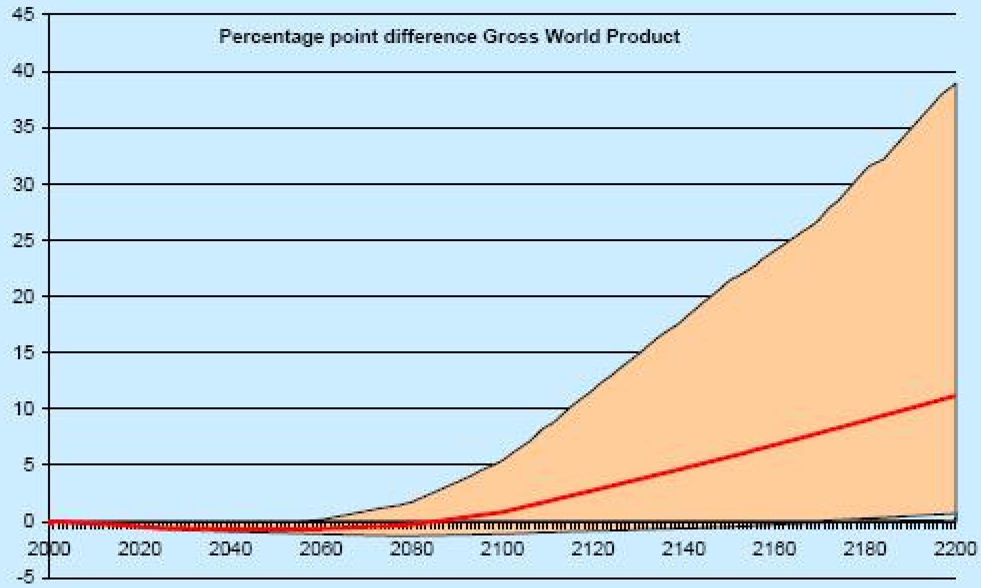
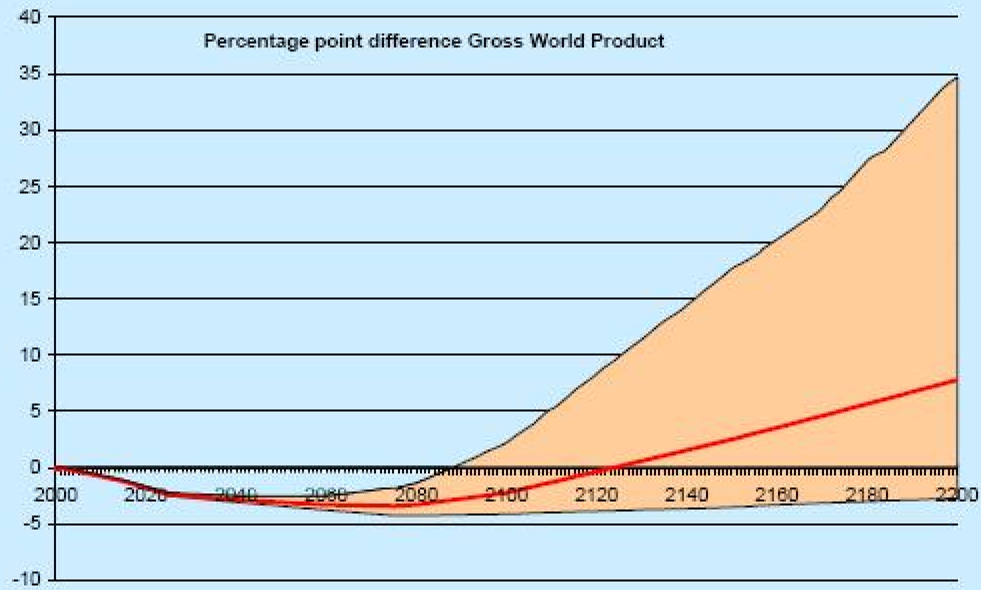


Figure 13.2 'Output gap' between the '550ppm CO_2e and 4% GWP mitigation cost' scenario and BAU scenario, mean and 5th – 95th percentile range



Appendix 5

Terms of Reference of the Garnaut Climate Change Review

To report to the Governments of the eight States and Territories of Australia, and if invited to do so, to the Prime Minister of Australia, on:

1. The likely effect of human induced climate change on Australia's economy, environment, and water resources in the absence of effective national and international efforts to substantially cut greenhouse gas emissions;

2. The possible ameliorating effects of international policy reform on climate change, and the costs and benefits of various international and Australian policy interventions on Australian economic activity;

3. The role that Australia can play in the development and implementation of effective international policies on climate change; and

4. In the light of 1 to 3, recommend medium to long-term policy options for Australia, and the time path for their implementation which, taking the costs and benefits of domestic and international policies on climate change into account, will produce the best possible outcomes for Australia.

In making these recommendations, the Review will consider policies that: mitigate climate change, reduce the costs of adjustment to climate change (including through the acceleration of technological change in supply and use of energy), and reduce any adverse effects of climate change and mitigating policy responses on Australian incomes.

This Review should take into account the following core factors:

- The regional, sectoral and distributional implications of climate change and policies to mitigate climate change;

- The economic and strategic opportunities for Australia from playing a leading role in our region's shift to a more carbon-efficient economy, including the potential for Australia to become a regional hub for the technologies and industries associated with global movement to low carbon emissions; and

- The costs and benefits of Australia taking significant action to mitigate climate change ahead of competitor nations; and

- The weight of scientific opinion that developed countries need to reduce their greenhouse gas emissions by 60 percent by 2050 against 2000 emission levels, if global greenhouse gas concentrations in the atmosphere are to be stabilised to between 450 and 550ppm by mid century.

Glossary

Carbon dioxide equivalent (CO_2e)

This is a measure used to convert all greenhouse gases to a common unit based on the equivalent global warming potential over a given period of each greenhouse gas relative to that of CO_2. The measure is determined by a gas's heat absorbing ability and decay rate

	Lifetime in the Atmosphere (years)	**100-year Global Warming Potential (GWP)**	**Percentage of 2000 Emissions in CO_2e**
Carbon dioxide	5-200	1	77%
Methane	10	23	14%
Nitrous oxide	115	296	8%
Hydrofluorocarbons	1-250	10-12,000	0.5%
Perfluorocarbons	>2,500	>5,500	0.2%
Sulphur hexafluoride	3,200	22,200	1%

During pre-industrial times emissions were determined to be mostly CO_2. so that measures of CO_2e are the same as the level of CO_2.

Cost Benefit Analysis (source Wikipedia) is an economic tool to aid social decision-making, and is typically used by governments to evaluate the desirability of a given intervention in markets. The aim is to gauge the efficiency of the intervention relative to the status quo. The costs and benefits of the impacts of an intervention are evaluated in terms of the public's *willingness to pay* for them (benefits) or willingness to pay to avoid them (costs). Inputs are typically measured in terms of opportunity costs – the value in their best alternative use. The guiding principle is to list all of the parties affected by an intervention, and place a monetary value of the effect it has on their welfare *as it would be valued by them.*

Damage function – the damage function is designed to capture stochastically the empirical assessments of other IAMs of the economic impacts of temperature increases. For higher temperature (above 3 to 4 deg C above pre-industrial levels) information is less reliable because the temperature increases are so much higher than human experience. The PAGE2002 model uses a function where damage as a fraction of consumption or income is

Damages ~ $\beta \{T_R/2.5\}^\gamma$
where
β is consumption loss at 2.5% deg C warming ,
T_R is the regional temperature increase and
γ is the damage exponent.

In the standard model used in the Review γ is 1.3 which implies fairly weak convexity. Many of the predicted impacts, such as the strength of hurricanes suggest that higher convexity could be assumed.

Externality – an action that has a harmful impact on people where no compensation is paid to those harmed by the action. There is therefore no incentive to correct the behaviour. An example is air pollution which has an impact on public health within a definable area. GHG emissions however have global impact.

IPCC Special Report Emissions Scenarios (SRES)

The IPCC has developed a series of scenarios for future development of the world over the next century. They provide a framework for projecting the future changes in greenhouse gas emissions without explicit allowance for reduction measures. The broad "storylines" for these scenarios are:

A1 – fast growth and technological development to 2050 followed by declining growth. There are 3 subgroups within this storyline with different assumptions for the take up of non-fossil fuel technologies.

A2 – basically the continuation of the current world with high economic and population growth up to 2050 with slow convergence of fertility rates between countries followed by declining growth.

B1 – convergent world moving to a service economy with resource efficient technologies.

B2 – between A1 and B1.

Marginal abatement cost (MAC) – cost of additional unit of reduction in CO_2 emissions.

Social cost - the total of private costs and external costs of production of a good or service. External costs include aspects like pollution that society will likely have to pay for in some way or at some time in the future, but that are not included in transaction prices.

Social cost of carbon

The present value of costs and benefits in monetary terms into the indefinite future of the emission of one unit of carbon.

Carbon comprises 27% of the atomic weight of CO_2 so that a SCC of $100/tonne C is equivalent to a SCC of $27/tonne CO_2. The atomic weight of carbon is 12 and of oxygen is 16.

The relative social cost of gases other than CO_2 will depend on their relative GWP over a given period and when that warming potential is effective. The latter determines the economic valuation of the damage done. For example, a gas with 10 times the GWP but is in the atmosphere for one-tenth the time, would have a lower social cost because it would have its effect while the total stock of GHG in the atmosphere is lower on average so its marginal impact will be less.

United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC is an international environmental treaty ratified at the 1992 Rio United Nations Conference on Environment and Development, the Earth Summit. Its stated objective is "to achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system."

The treaty as originally framed set no mandatory limits on greenhouse gas emissions for individual nations and contained no enforcement provisions; it is therefore considered legally non-binding. The treaty included provisions for updates (called "protocols") that would set mandatory emission limits. The principal update is the Kyoto Protocol signed in 1997 in which the developed countries agreed on targets for reductions in greenhouse gas emissions. The Protocol came into force when developed countries representing 55% of CO_2 emissions of this group's total emissions ratified their commitment to comply with the Protocol.

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