Stern Review: Frequently Asked Questions

The scientific basis and overall approach of the Review

1. Is there a sound scientific basis for the analysis in the Review?

The basic science on climate change is very well established. The underlying mechanisms were identified in the 19th century.

The Review is based on evidence from the IPCC Third Assessment Report, and on recent published science. A summary of recent scientific research may be found in 'Avoiding Dangerous Climate Change'[1].

The science underlying the Review was criticised in Byatt et al (2006)[2]. We have issued a detailed rebuttal of these arguments in World Economics, April-June 2006, which can be found on our website at

http://www.hm-treasury.gov.uk/media/5E1/FB/stern_reply_worldeconomics.pdf.

2. How does the Review account for the uncertainties in the science?

The Review is explicit about the treatment of risk and uncertainty in assessing the impacts of climate change. Indeed, a major feature of the Review is that the economics of risk is placed at the heart of the economics of climate change. The Review has worked with quantitative approaches, drawing on recent peer-reviewed science, in many areas.

One important area is understanding the link from concentrations to temperature rise. We look at recent scientific evidence on the probabilities of reaching certain temperature thresholds at different stabilisation levels. These probabilities, which have only recently been available, provide a crucial underpinning for the economics of the analysis of risks. The work of a recent Hadley Centre study, and from the IPCC Third Assessment Report, form the basis of this analysis, although we have also looked at other projections, some of which show much higher risks at the upper end.

We also consider how emissions influence atmospheric concentrations – for example, if carbon sinks weaken, we can afford to emit less to reach the same stabilisation goal

And we look at how temperature feeds through to direct impacts – for example, carbon fertilisation could make a large difference to the impact of temperature rise has on agricultural yields; recent science has been more pessimistic about the extent to which carbon fertilisation would offset temperature effects.

3. Why are your concentration levels given as CO2e?

The carbon dioxide equivalent (CO2e) level of greenhouse gases expresses the total warming effect (the radiative forcing) of all Kyoto greenhouse gases in terms of the equivalent concentration of carbon dioxide. By this definition, the current level of greenhouse gases is 430ppm (CO2e). This level shapes, with future emissions, the

[1] 'Avoiding Dangerous Climate Change', ed Schellnhuber (2006). Cambridge University Press
[2] The Stern Review 'OXONIA Papers': A critique: Ian Byatt, Ian Castles, David Henderson, Nigel Lawson, Ross McKitrick, Julian Morris, Alan Peacock, Colin Robinson & Robert Skidelsky, World Economics, April-June 2006

impacts. Expressing greenhouse gas levels in terms of only carbon dioxide masks the important contribution to the problem from other gases created by human activities. Throughout the report we often also give levels of CO2 only.

Estimates of the impacts of climate change

4. How do you analyse the impacts of climate change?

The foundation of the Review's analysis of impacts is a detailed assessment of the impacts of climate change at different levels of temperature rise. Whilst most studies have focused on levels of warming of around 2 – 3°C above pre-industrial, less is known about how the environment and human society will respond to larger increases in temperature. A warming of 5°C on a global scale – which could well be reached on a scenario of business-as-usual emissions from now to the end of the century – would be far outside the experience of human civilisation.

The analyses presented in Chapters 3 - 5 of the Review demonstrate the great dangers of allowing temperatures to continue to rise, in terms of environment, the way we live our lives and economic growth. Many of the impacts of climate change increase in severity with temperature. Examples include the damage caused by hurricanes, the frequency of extreme events, effects on agricultural production, and heat-related mortality. Impacts can interact, bringing about rapid increases in damages at high temperatures. An example is that rising levels of pests in some areas may aggravate declines in agricultural production from other causes.

In addition, current understanding suggests that at high levels of warming, the risks of major, irreversible changes to the climate, ecosystems and society are very real. These include physical changes, such as a collapse of ocean currents, and also the risk of major societal changes, such as mass migrations and political and social instability.

Putting all these impacts together builds a strong picture of impacts rapidly rising with temperatures. High temperatures are likely to generate a hostile and extreme environment for human activity in many parts of the world. From this analysis and looking forward to the estimates of costs of mitigation points to the conclusion that the stabilization range for concentrations of GHGs should be in the range 450-550ppm (CO2e).

We also look at ways to estimate the costs at an aggregate level, which are discussed below. They support the above conclusion for the stabilisation range. We should stress, however, that we devote more space and attention to the disaggregated analysis and broad appreciation of risks and judge that these arguments should be the first call on our attention.

5. How did you get to the 5 – 20% estimate of the damages of climate change?

We find that the costs of climate change, averaged over time, over the regions of the world and across a wide range of scenarios, are equivalent to a loss in average world consumption of 5-20% per year averaged over time and possible outcomes.

These figures were derived using the PAGE model, which we chose because it allows stochastic analysis, and because it covers much of the range of possibilities from earlier models. They are illustrative figures based on a very aggregated model run into the next century and beyond; they should not, as the Review emphasises strongly, be taken too literally.

Our estimate of 5% is based on the climate science presented in the IPCC's Third Assessment Report in 2001. It does not assign any value to the impacts of climate change on human health and the environment.

The estimates rise as a number of different dimensions of risk and impact are included.

- The estimate of damages rises to 7% when the model is adjusted to incorporate the possibility of amplifying feedbacks in the climate system (weakened carbon sinks and increased natural methane release). This is just one example from the scientific literature on increased risks published more recently than 2001.

- The estimate of damages rises to 11% for the original climate assumptions, or to 14% with the increased climate risk, when the economic value of impacts of human health and the environment are included. The Review warns that such valuations should be treated with caution and for the most part in other chapters, looks at disaggregated effects.

- The estimate of damages is likely to rise again, by more than a quarter, if intra-temporal income inequality is taken into account.

As the Review makes clear, the role of integrated assessment models is to give an illustration of the potential effects of climate change. Modelling of the economic impacts of climate change over very long time horizons cannot give precise results. The value of the approach is that it allows the investigation of the role of different specifications of model structure and ethical assumptions. The ethical judgements which have to be examined include those concerning how society should weight impacts on different generations (see question on discounting, below).

The impacts have been expressed using a technique which allows averaging over time, risk and country in a way that allows us to compare them with the costs of mitigation.

The Stern Review paper "Technical Annex to Postscript", available from the website **www.sternreview.org.uk**, gives a detailed explanation of the methodology used.

6. Why are your damage estimates higher than some other studies?

Our estimates of damage from business-as-usual are higher than some previously published for the following reasons[3].

First, we treat aversion to risk explicitly – this issue is all about risk. Here, we use economic techniques standard in the economics of risk.

Second, we use the more recent literature, from the science, on the probabilities, which points to significant risks of temperature increases above 5°C under business-for-usual by the early part of the next century. Previous studies have focused on temperature increases of 2 or 3°C. The damages from 5°C would be very much higher – damages rise much faster than temperature.

Third, we suggest that the ethics of the problem argue against substantial 'pure-time' discounting of the welfare of future generations (see discussion of discounting, below).

[3] Again see the Stern Review paper Technical Annex to Postscript, available from **www.sternreview.org.uk** for further detail.

Finally, we take account of the disproportionate impacts on poor regions, reflecting the fact that those in poverty will feel losses in income more keenly. Few existing studies include all these factors, and as a result their estimates of the damages tend to be lower. The modelling paper on **www.sternreview.org.uk** shows that there are some respects in which our assumptions underestimate the damage by others which give lower estimates than the previous literature.

Our illustrative modelling-based estimates are complementary to a more detailed analysis of economic impacts at a disaggregated level, based on the latest science and on research commissioned for the Review. This disaggregated work forms the basis of our conclusions, which are then reinforced by the model estimates.

7. Do your damage estimates take account of adaptation?

In Chapters 3 to 5 of the report, when highlighting the risks of climate change, estimates of the costs assume individual-level actions to reduce damages from climate change (autonomous adaptation), but little policy intervention on adaptation. All figures are presented on this basis in these Chapters. In Part V, we consider how adaptation policies could reduce the costs of climate change identified in Chapters 3 to 5. In the economic modelling of climate-change impacts (Chapter 6), which contains the estimates of impacts on average world consumption, it is assumed that significant adaptation occurs. The model used (PAGE) assumes that 90% of the impacts are adapted to in rich countries, and 50% in poor countries. Our assessment includes the costs of adaptation in the damages.

8. What discount rate do you use?

The decision on discounting depends on two factors: first, how to take into account the fact that people are likely to be richer in the future; and second, whether the future should be discounted simply because it is the future.

We discount in the standard way to allow the possibility that people will have higher consumption in the future. Climate change implies that strongly divergent paths for future growth are possible. The use of a single set of discount rates for all paths is inappropriate when looking at non-marginal changes.

The degree of discounting depends on attitudes to income distribution, which are captured by the elasticity of the marginal utility of consumption. We use an elasticity of one, in line with some empirical estimates. For this case, the contribution to the discount rate is equal to the rate of growth of consumption of the path. This reflects an assumption that society is moderately averse to income inequality and therefore is more worried about adverse impacts that fall on poorer generations. If society were more strongly averse to income inequality, it would be appropriate to use a higher multiple of the average growth rate.

In addition, we carefully examine the case for discounting the future just because it is the future – which in economic terms is known as pure time preference. This requires a consideration of the ethical issues involved in comparing the incidence of costs and benefits between generations, some of which are distant in time. We argue – in line with economists including Ramsey, Sen, Pigou and Solow – that the welfare of future generations should be treated on a par with our own. This means that the only justification for a positive rate of pure time preference in assessing the impacts of climate change is the possibility that the human race may be extinguished. As the possibility of this happening is low, we assume a low rate of pure time preference, 0.1%, which corresponds with a 90% probability of humanity surviving a 100-year period. Higher probabilities of survival would imply a still lower rate. There are other

approaches to pure time discounting and references are given in the Review (Chapter 2 and the appendix) and in the "Modelling Paper" on **www.sternreview.org.uk**.

The average discount rate used in the modelling exercise is then the combination of these two elements: the average growth rate over the relevant time horizon for the particular path being examined (in the case where the elasticity of the marginal utility of consumption is one), plus the 0.1% pure rate of time preference.

Many previous studies have used higher rates of pure time preference, which are similar to those used for evaluating other kinds of investments. However, we argue that this disinvestment in the environment cannot be considered in, say, the same way as an economist would consider an investment in a railway. A railway can be replaced or redesigned, it can become obsolete or redundant. In other words, the probability of survival depends on the context. In this case the context is that of the whole planet.

9. What is your estimate of the social cost of carbon?

The Review makes a calculation of the damage done over time (suitably discounted) by a tonne of CO2 emitted this year, if the world continues on a business-as-usual scenario. Economists call such estimates the 'social cost of carbon' (SCC). It reflects the model used to assess damages over time and the economic and ethical judgements made about parameter settings.

We first estimate the SCC for a scenario of unmitigated climate change, where the loss of consumption expressed per year, averaging over time and over different possible outcomes, lies in the middle of the 5-20% loss of global consumption explained above. In this case, the SCC is $85/tCO2 (and rising over time). This is higher than many estimates in the literature, because of our approach to discounting, risk aversion, and the latest science.

If the world achieves stabilisation at a level that reduces the risks and damages of climate change, the SCC will be much lower, perhaps $25-30/tCO2, now and rising over time. This is a better indication of the level of the carbon price that could be needed to implement climate-change policy, assuming that effective global policy action is taken. This underlines that estimates of the SCC must be specific about the path being considered – different paths have different SCCs. This also emphasizes the strong link between the SCC and the emissions path assumed.

Estimates of the costs of mitigation

10. What is your estimate of the cost of stabilising the climate?

The Stern Review estimates that the cost of reducing emissions along a path consistent with stabilisation at 550ppm CO_2e or below will be in the region of 1% of GDP by the middle of this century, with a range of plus or minus 3% around this central estimate. This figure reflects estimates from both a technology-based resource-cost approach carried out for the Stern Review by Dennis Anderson and an analysis of a range of results from large-scale economic models.

The range of estimates reflects uncertainties over factors such as the pace of technological change and the evolution of fossil-fuel extraction costs, as well as the degree of flexibility in exploiting low-cost mitigation options internationally. The costs are likely to be in the higher end of the range if policy is poorly applied across the world, or the stabilisation target is more ambitious.

The costs represent a one-off increase in the cost or price index of around 1%, primarily from adjustments in the use of energy. This means that there is no reason why strong mitigation should curtail growth. Thus we can be 'green' and grow. On the other hand unmitigated climate change will eventually derail growth.

11. How should a cost of 1% of GDP be interpreted?

Our estimates suggest that the costs would rise to around 1% of GDP by the middle of the century.

Global GDP is currently around $35 trillion, so if the full 1% were applied to the current period, it would imply around $350 billion in costs. Global GDP is likely to be around $100 trillion by 2050, so this would mean annual costs in the order of $1 trillion by then.

These costs are not trivial in absolute terms, but they will not disrupt economic growth. The overall impact can be thought of as equivalent to a one-off increase in the average price level of 1%. Since it may be interpreted as a cost or price index we should see the 1% as applying to either consumption or income.

The costs of inaction would be likely to be much more significant in terms of damage to the world economy.

12. How will the costs of tackling climate change be distributed around the world and between sectors?

The cost may be unevenly distributed amongst countries. For equity reasons, rich countries may at least initially need to take on more of the costs. For illustration, if the costs of mitigation are 1% of global GDP, then if the rich countries agreed to pay 20% more in the initial decades (1.2% of GDP), then this would allow poorer countries – accounting for 80% of the world's population – to pay only 0.2% of GDP.

If some countries take action that is much more significant than others over long periods of time, this may lead to impacts on the competitiveness of some firms or sectors, particularly in energy-intensive industries. It is important to use quantitative analysis to assess the size of these impacts, and to find ways to reduce the problems. If all countries act in a broadly similar way, there will be no impact on competitiveness or on firms' decisions to invest in particular locations. For some industries, a global sectoral agreement in advance of a broader international agreement could offer opportunities to co-ordinate efficient and effective action.

Taking no action to reduce emissions will also penalise some sectors more than others – for example, as the climate changes the spatial distribution of tourism and agriculture.

13. What modelling estimates did you take account of?

We examined a very broad range of modelling studies, which includes exercises undertaken by the Energy Modelling Forum (EMF) and US Climate Change Science Program (USCCSP) as well as work commissioned by the Intergovernmental Panel on Climate Change (IPCC). Taken together, the studies suggest the expected annual cost of achieving emissions reductions, consistent with an emissions trajectory leading to stabilisation at around 500-550ppm CO_2e, are likely to be around 1% of GDP by 2050, if policies are sensible and stimulate the required technological advances.

We also commissioned Terry Barker to undertake a detailed 'meta-analysis' using a combined three-model dataset. These mostly reaffirmed the findings of other studies, with estimates for 2050 clustered in the range –2 to 5% of GDP. The full range of estimates drawn from a variety of stabilisation paths and years extends from –4% of GDP (that is, net gains) to +15% of GDP costs. However, we judged many of the outlying estimates to be either inapplicable at the global level, or inconsistent with the historical evidence (particularly on the likely evolution of the costs of technologies).

14. Do you take account of co-benefits ("win-wins") in other areas such as reduced air pollution?

Our central estimate on the basis of resource costs of lower-carbon technologies of 1% does not take account of co-benefits, for example in terms of reduced ill health and environmental damage from air pollution and increased energy security.

Some of the macro-models do build in estimates of these co-benefits. These models find that co-benefits can be valued at up to 1% of GDP.

15. Do you account for the costs of climate-change damages that will occur even if action is taken to reduce emissions?

The Review makes it clear that mitigation at 450-550ppm CO2e will not remove all the risks from climate change. But our assessments of the cost of action reflect the net damages we can avoid by going from business-as-usual to 550ppm CO2e.

Our disaggregated analysis of impacts suggests that damages and risks rise more rapidly than temperatures. Stabilising at or below 550ppm reduces the chances of temperature rises of 4 to 5°C and above, at which levels some of the worst impacts occur, and therefore reduces the risks very significantly.

As an illustrative example of the scale of this effect, we give the PAGE estimate of costs at 550ppm as a 1.1% reduction in consumption, now and forever, on a "broad impacts, standard climate sensitivity" case. This is about ten times lower than the corresponding "business as usual" case (11%). Stabilisation at 450ppm CO2e would reduce this estimate to 0.6%.

We also take account of the fact that spending more on adaptation can reduce the impacts of climate change and should be part of the policy response.

16. How do your cost estimates compare with those of the IPCC?

The IPCC Fourth Assessment Report is still work in progress, and no numbers from it have been published. However, we are confident that they will publish a range for mitigation costs next year in which our range will be centrally placed.

Adaptation

17. Isn't adaptation a more cost effective response than mitigation?

Adaptation is a critical part of the response to climate change, not least because the world is already locked into further temperature rises over the coming decades as a consequence of past emission reductions.

However, whilst adaptation is necessary and sensible is not a cheap option. The costs of making new infrastructure and buildings more resilient in OECD countries are difficult to estimate but we indicate, on the basis of previous studies, a range of $15-150 billion each year, even for lower levels of temperature increase. Adaptation in developing countries is likely to cost tens of billions of dollars a year, according to the World Bank.

And adaptation can only mute the impacts of climate change; there are limits to what it can achieve. Impacts on ecosystems, for instance, may be impossible to avoid. This is particularly true at higher levels of temperature increase, where the impacts will be more severe, and the risks of abrupt irreversible impacts higher. Mitigation is the only way to reduce these risks.

18. Economic growth will increase the resilience of poor people to climate change. Isn't development the best solution?

Economic development brings the diversification, flexibility and human capital that are crucial components of adaptation to the adverse impacts of climate change. However, in the absence of action to control emissions, greenhouse gases will quickly reach concentrations that pose real and large risks for developed and developing countries alike. And in the absence of strong mitigation policies, the private sector will have little incentive to deliver the low-carbon technologies that will inevitably be needed to cut emissions in the future.

Action to mitigate climate change can be taken at significant, but manageable, costs. It will not cap the aspirations for growth of rich or poor countries.

At the same time, good development practice supports adaptation to reduce the risks of the climate change that can no longer be avoided, – for example, promoting overall development, better disaster management and emergency response arrangements, researching more climate-resilient crops and taking steps to eradicate malaria and other vector-borne diseases.

The scale of the challenge and the necessary costs of adaptation make it more urgent than ever for developed countries to honour their existing commitments to double aid flows by 2010 – made in Monterrey in 2002, and strengthened at EU Councils in June 2005 and at the July 2005 G8 Gleneagles Summit.

International action

19. How can the climate change be tackled if the larger countries take no action?

All countries will have to play a part in tackling climate change. The larger countries are already taking significant steps. The EU has taken the lead in establishing the world's largest cross-border emissions trading scheme, which is already providing a market to encourage investment in low-carbon options in Europe and in the developing world. China's 11th Five Year Plan contains a very ambitious goal to reduce the energy intensity of output by 20% from 2006-2011, and India is also placing increased emphasis on renewable energy and energy efficiency. The US is investing in R&D, and some states are going further including through support for the deployment of renewable energy and through the use of emissions trading.

The challenge is to build on diverse national circumstances and approaches, and to create international links that allow the problem to be tackled in the most cost-effective way. There are opportunities to reduce the costs of mitigation through international co-operation, for example through emissions trading, through pooling investments in larger R&D projects, through co-operation to create larger markets for the deployment of lower carbon technologies, and through the international co-ordination of product standards.

20. Rich countries are responsible for past emissions but poor countries are hardest hit. How should international action tackle the problems of the poorest countries?

Those countries responsible for the stock of greenhouse gases in the atmosphere now have a responsibility to help the poorest countries to adapt to climate change. Adaptation to climate change will increase pressure on already scarce resources.

International action to support adaptation includes support for good development practice, and it is important that rich countries honour the commitments they have made to double aid flows by 2010. There are also specific areas where international co-operation is relevant – including research into new crop varieties, better climate data and regional modelling of impacts.

International action to reduce emissions is also essential to protect all countries from even greater risks of climate impacts. Emissions trading is a powerful way to promote co-operation with between rich countries and the growing economies that have relatively cheap opportunities to cut emissions. The Clean Development Mechanism is already channelling some investment to developing countries, and these flows should be transformed and scaled up.

Access to energy for the poorest countries is also an important component of development. The Clean Energy Investment Frameworks developed by the World Bank and Regional Development Banks provide a key opportunity to expand access to clean energy for the poor.

Specific questions

We would be very grateful if readers could notify us of any typographical or other errors in the Review.

21. You state the cost of US hurricanes at temperatures of 3°C above pre-industrial levels as 0.13% and 1.3% of US GDP in different places in the report. Which is correct?

The correct figure is 0.13%. There is an error in Chapter 5, pg. 139, which cites the cost as 1.3%. An Errata page will be published to cover this and any other typographical errors.

22. Are your estimates of the cost of flooding in the UK consistent with the Government's own estimates?

In Part II of the report, estimates of the costs of UK flooding are cited from a UK government study, stating that the cost of flood damage could rise from 0.1% of GDP to 0.2 - 0.4% if global temperatures rise by 3 – 4°C. This assumes no policy intervention on adaptation. All figures are presented on this basis in Part II to demonstrate the scale of

potential damages with no policy intervention. In Part V, we consider how adaptation policies could reduce the costs of climate change. Here, we refer to one study that shows that the costs globally of sea level rise could be brought down substantially if appropriate adaptation policies are put in place. This demonstrates the importance of adaptation.

About the Review

23. Where can I get a copy of the Stern Review?

The Stern Review was web published on 30 October, and can be downloaded at ww.sternreview.org.uk.

Hard copies will be available from January at a charge of c. £29.99 + £3.50 postage and packing (quoting ISBN number: 0-521-70080-9). Copies can be ordered from Cambridge University Press via the website

http://www.cambridge.org/9780521700801

by fax on +44 (0)1223 315052 or post from the following address: Science Marketing, Freepost, Cambridge University Press, The Edinburgh Building, Cambridge, CB2.

24. How can I contact the Review team?

Please email any enquiries to **stern.review@hm-treasury.gov.uk**.

There is also a telephone number for media enquiries: 0044 207 270 6280.

25. Will you respond to comments made on the Review?

A brief paper responding to some of the issues raised was included as a postscript to the Review and published shortly after the Review. Subsequent responses to academic critiques will also be published on the website.