STERN review ON THE ECONOMICS OF CLIMATE CHANGE

What is the Economics of Climate Change?

Discussion Paper

31 January 2006

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Executive summary

Climate change is a serious and urgent issue. The underlying science of global warming through greenhouse gases has been understood for more than a century. There is now an overwhelming body of scientific evidence that human activity is increasing the concentrations of greenhouse gases in the atmosphere, and causing warming. We are already seeing significant impacts. There remain uncertainties about the nature and scale of impacts in the longer term, but the most recent science indicates that some of the risks are more serious than had first appeared.

The problem is global in its cause and consequences. Greenhouse gases have broadly the same impact on the climate wherever in the world they are emitted. And in terms of its consequences, no region will be left untouched. But impacts will be unevenly felt throughout the world. Some of the most severe impacts will be felt in the poorest countries that are least able to adapt to the changes.

The economic challenges are complex. At its most basic level, climate change is an externality: the emission of greenhouse gases damages others. But these costs will be felt over a long period and over the entire globe; their exact nature is uncertain; they interact with other market failures and imperfections; and those most affected – future generations – are not able to speak up for their interests. This points to a long-term international collaborative response. Effective collaboration will require a shared understanding of the incentives and institutions needed, and careful attention to the complex ethical issues involved.

The current pathway of emissions is unsustainable. Economic growth, particularly in the developed world, has driven past increases in greenhouse gas emissions including from energy use, agriculture and deforestation. Much of the future growth in emissions will be in developing countries. It is clear that we will have to go far beyond the actions currently agreed if we are to stabilise greenhouse gases at any acceptable level.

Climate change itself may impede growth and development. Climate change has profound implications for the environment in which social and economic activity takes place. We need to understand how economic growth and other indicators of human development may be affected. Some of the most severe impacts will be felt in the poorest countries, which strengthens still further the case for international action to fight poverty and promote development. All countries will want to take account of the implications of climate change for future growth.

We can still take action to avoid the worst impacts of climate change. In the energy sector, energy conservation, changes to the mix of economic activity, and the development and deployment of technologies will all play a role. Some sectors will be more challenging than others.

Effective action requires an understanding of how mitigation may affect economic growth. This depends on how quickly current energy production and consumption patterns are shifted, on how co-ordinated countries are in their actions, and on how far action eliminates energy inefficiencies and promotes innovation.

A combination of policies, institutions and changes in preferences will be needed. Key policy instruments include taxes, property rights and regulation; all three play a role in most advanced countries. Strong institutions are needed to underpin the response to climate change, along with discussion and education to shift preferences over time and build an understanding of the benefits of a stable climate, and of collaboration if this is to be achieved.

The private sector will respond if governments set clear, long-term and credible incentives. Policies should take into account the complexities and imperfections in energy markets, including possible responses of fossil fuel prices, and the importance of other energy policy goals including security of supply and access to energy.

Uncertainties and irreversibilities permeate the story. Uncertainty over the consequences of climate change poses a challenge for international collective action, and may influence the choice of different policy instruments. The possibility of serious adverse consequences may justify more extensive action now than central projections alone would suggest. Irreversibilities are also a key part of the story, both in terms of the potential for irreversible changes in the climate, and in terms of large, long-lived capital investments that will lock in emissions for decades to come.

Climate change requires an international response. This should be based on a shared understanding of the implications for different countries of the consequences of different arrangements. If groups of countries act together, the impacts of particular policy instruments on the competitiveness of individual sectors can be managed more successfully.

Incentives need to be in place to support action in fast-growing developing countries. We must find ways of tackling climate change that are consistent with continued economic growth and development. Developed countries, which bear most of the historical responsibility for the problem, should show leadership. The UK and EU have a vital role to play in generating the multilateral action that is crucial for an effective response.

An equitable international response to climate change must include action on both adaptation and mitigation. Adaptation and mitigation are not choices: substantial climate change is already inevitable over the next 30 years, so some adaptation is essential.

Introduction

1. A major review of the economics of climate change under the leadership of Sir Nicholas Stern was announced at the end of July 2005, reporting to the Chancellor of the Exchequer and the Prime Minister.

2. The terms of reference are available at www.sternreview.org.uk.

3. The review began work in Autumn 2005 and will report in Autumn 2006.

4. We were grateful for the more than 200 submissions to the Call for Evidence that closed in December. These submissions are now available on our website.

5. We would welcome reactions to this paper by 17 March 2006 to our email address: oxonia.responses@sternreview.org.uk, or by post to:

Stern Review Team
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Part One: The science and the international response

6. Climate change is a serious and urgent issue. There is an overwhelming body of scientific evidence that human activity is causing warming. The climate is changing, and we are already seeing significant impacts.

7. There remain uncertainties about the nature and scale of impacts in the longer term, but the most recent science indicates that some of the risks are more serious than previously thought. Some risks, if they were to crystallise, could be irreversible and accelerate the process of global warming, for example release of greenhouse gases from thawing permafrost or the dieback of the Amazon forest.

8. The problem is global in its cause. Greenhouse gases (GHGs) have the same impact on the climate wherever in the world they are emitted. Some of them, including carbon dioxide, stay in the atmosphere for more than a century. And it is global in its consequences: no region will be left untouched.

9. But impacts will be unevenly felt throughout the world. In terms of number of people affected, some of the most severe impacts will be felt in the poorest countries that are least able to adapt to the changes.

10. Part One will therefore:

    - provide a brief overview of the science of climate change and its likely impacts on socio-economic systems,
    - note the international response to date, and
    - highlight the nature of the problem in terms of the implications from the science for the key economic issues and the structure of the policy problems, and the tools we need to understand the economics of climate change.

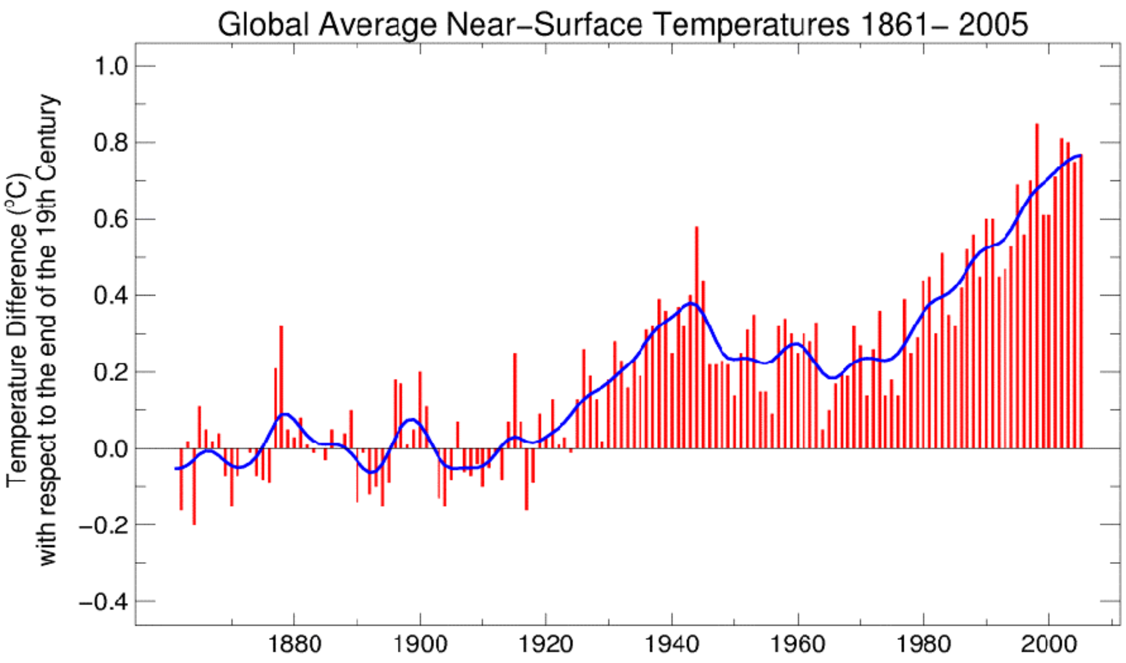
11. Further details (including full references) are available in the Technical Annex on the science that accompanies this paper.

Section 1.1: What is climate change and why does it matter?

The nature of the evidence for climate change

12. The climate is changing, and we are already seeing significant impacts.[1] Measurements compiled from thousands of weather stations all over the world support the picture of a warming planet. The Earth has warmed on average by 0.7°C globally since 1900 (Figure 1.1[2]). All ten warmest years on record have occurred since 1994. The rate and scale of 20th century warming has been unprecedented for at least the past 1,000 years.[3] The rate of sea level rise has been accelerating, doubling to 2 mm per year over the past 150 years.[4]

Figure 1.1



Source: Hadley Centre, Dec 2005

13. The evidence that this change is being induced by human activity is growing ever stronger. Climate models now show with a very high degree of confidence that human-induced increases in carbon dioxide and other greenhouse gases are

[1] See, for instance, Intergovernmental Panel on Climate Change (2001) Climate change 2001: summary for policymakers, Cambridge University Press, Cambridge, http://www.ipcc.ch; Arctic Climate Impact Assessment (ACIA) (2004) Impacts of a warming Arctic, Cambridge University Press, Cambridge; European Environment Agency (2005) Vulnerability and adaptation to climate change in Europe, http://reports.eea.eu.int/technical_report_2005_1207_144937/en; Schellnhuber HJ (ed.) (2006) *Avoiding dangerous climate change*, Cambridge University Press, Cambridge

[2] The blue line is the result of using a 21-year binomial filter to smooth the annual data.

[3] International ad hoc detection group (2005) Detecting and attributing external influences on the climate system: a review of recent advances, *Journal of Climate* **18**:1291-1314

[4] Miller KG, Kominz MA, Browning JV *et al.* (2005) The Phanerozoic Record of Global Sea-Level Change, *Science* **310**: 1293 - 1298

responsible for much of the recent warming we have observed.[5] It is only when both natural factors and man-made influences such as air pollution and rising greenhouse gas concentrations are included that the models accurately predict the changes we have seen.

14. The basic physics of climate change is well established. Fourier, Tyndall and Arrhenius established the key elements of the greenhouse effect in the 19th century. The natural greenhouse effect has operated for billions of years, making our planet habitable by keeping the Earth's temperature around 30°C warmer than it would be without this "greenhouse effect". What is new in the last 150 years is the rapid increase in greenhouse gases that has accompanied industrialisation. Since 1750, carbon dioxide levels in the atmosphere have increased by around 30% from 280 parts per million (ppm) to over 380 ppm today.[6] Current levels are higher now than at any time in at least the past 650,000 years.[7]

15. International bodies, particularly the Intergovernmental Panel on Climate Change (IPCC), have been consolidating the scientific understanding that underpins international collaboration for around two decades. Scientists are now able to assess the likely range of warming for a given level of carbon dioxide in the atmosphere (Figure 1.2). These average figures mask changes in the distribution of climate in space and time. Continental areas are expected to warm by more than the average (2.2 – 6.2°C by 2100) and some of the largest changes will be seen in the Arctic (3.6 – 11.4°C by 2100). These changes will also be accompanied by changing patterns of rainfall and more extreme weather events (heatwaves, droughts, floods).

Figure 1.2. *Increase in global temperature by 2100 relative to pre-industrial levels for different stabilisation levels (expressed as CO_2 equivalent).*

Stabilisation Level (CO_2 equivalent)	**Temperature change - based on IPCC 2001 climate models**	**Temperature change - based on 2004 Hadley Centre ensembles**
400ppm	1.2 - 2.5°C	1.6 - 2.8°C
450ppm	1.3 - 2.7°C	1.8 - 3.0°C
550ppm	1.5 - 3.2°C	2.2 - 3.6°C

Source: Based on den Elzen and Meinhausen (2005). Assumptions underpinning calculations are explained in detail in Figure A3 in the Technical Annex.

16. While there remain some uncertainties about the scale of warming in coming decades, the most recent science indicates that some of the risks may be more serious than previously thought. For instance, air pollutants may have masked the

[5] Intergovernmental Panel on Climate Change (2001) Climate change 2001: summary for policymakers, Cambridge University Press, Cambridge, http://www.ipcc.ch

[6] Intergovernmental Panel on Climate Change (2001) Climate change 2001: summary for policymakers, Cambridge University Press, Cambridge, http://www.ipcc.ch

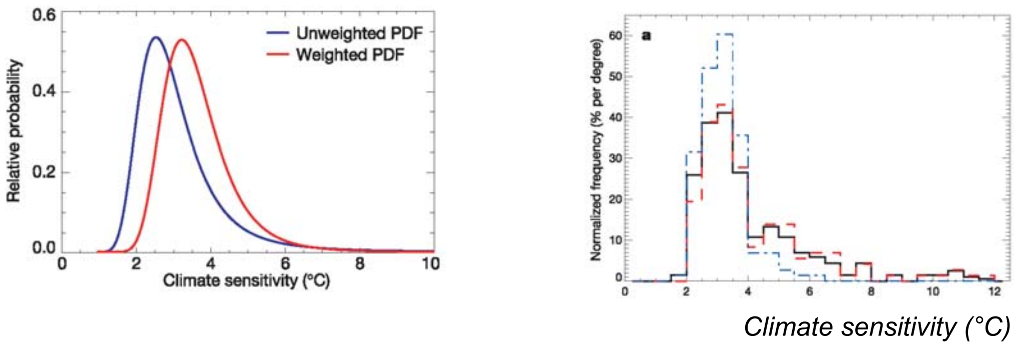
[7] Siegenthaler U, Stocker TF, Monnin E, *et al.* (2005) Stable carbon cycle-climate relationship during the late Pleistocene, *Science* **310**: 1313 - 1317

strength of the climate's response to greenhouse gases to date, meaning that a decline in air pollution in future could lead to a faster rate of warming.[8]

17. Some of the potential risks could be irreversible and accelerate the process of global warming. Melting of permafrost in the Arctic could lead to the release of huge quantities of methane. Dieback of the Amazon forest could mean that the region starts to emit, rather than absorb, greenhouse gases. These feedbacks could lead to warming that is at least twice as fast as current high-emissions projections,[9] leading to temperatures higher than seen in the past 50 million years. There are still uncertainties about how much warming would be needed to trigger these abrupt changes. Nevertheless, the consequences would be catastrophic if they do occur.

18. The nature of the scientific evidence marshalled in climate change models is different from that common in empirical economic models, with their focus on parameter estimation and curve fitting. By contrast, the science models (covering a broad range of phenomena, not just temperature) are essentially based on the laws of physics and chemistry. While some of their parameters are uncertain, 'goodness of fit' is only one of the criteria used to select their values. Recent approaches have investigated physical uncertainties in the climate system by varying parameters within climate models and running ensembles of these models (Figure 1.3).[10] More plausible outcomes (judged by their representation of current climate) are weighted more highly in the probability distributions produced.

Figure 1.3. *Probability distributions of climate sensitivity (global temperature increase for a doubling of carbon dioxide)*



a) Source: Hadley Centre (2004)

b) Source: climateprediction.net (2005)

19. Debate on climate science will continue, as with any other academic discipline. It is important to be aware of alternative hypotheses, while recognising that the overwhelming weight of scientific opinion supports the view that climate change represents a real and growing threat. While it is not for us to evaluate the detail of specific scientific debates the weight of the evidence and the magnitude of the

[8] Bellouin N, Boucher O, Haywood J, *et al.* (2005) Global estimate of aerosol direct radiative forcing from satellite measurements, *Nature* **438**: 1138-1141

[9] Hadley Centre (2005) Stabilising climate to avoid dangerous climate change, http://www.metoffice.com/research/hadleycentre/pubs/brochures/2005/CLIMATE_CHANGE_JOURNAL_150.pdf

[10] Murphy JM, Sexton DMH, Barnett DN, *et al.* (2004) Quantification of modelling uncertainties in a large ensemble of climate change simulations, *Nature* **430**: 768 – 772

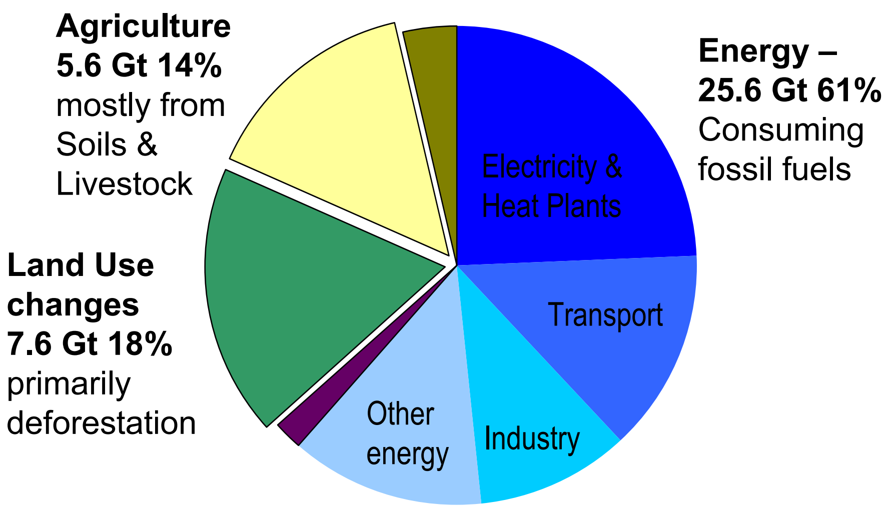
issue, all demand a serious response in terms of an analysis of appropriate policy approaches. That is the task of this Review.

What are the drivers of climate change?

20. Emissions of greenhouse gases have been the key factor in climate change for at least the past 50 years. Carbon dioxide emissions from burning fossil fuels have grown from 6 Gt in 1950 to 24 Gt in 2004.[11] Total global emissions, including all greenhouse gases, agriculture and land use change may now be approaching 45 Gt CO_2-equivalent per year.[12]

21. Most of these emissions are created by burning fossil fuels for energy in power and heat generation and transport, and by changes in land use (particularly deforestation) and from agriculture (Figure 1.4). Emissions from burning fossil fuels for the power and transport sectors have been increasing for most of the 20th century, with a substantial upturn in the 1950s. These are core activities in our economies, and energy use has tended to grow in line with economic activity.

Figure 1.4. *Global emissions of greenhouse gases come from a wide range of sources.*



Source: World Resources Institute. Chart shows source of all greenhouse gases in 2000 (CO_2 equivalent). The unlabelled segments are industrial processes (purple) and waste (olive).

22. The reference scenario[13] in the International Energy Agency (IEA)'s 2005 World Energy Outlook projects an increase of over 50% in global energy-related CO_2 emissions by 2030. Developing countries will account for almost three-quarters of this increase.

[11] Source: World Resources Institute (2005) Navigating the numbers http://climate.wri.org/navigatingnumbers-pub-4093.html

[12] Greenhouse gases are converted to a common unit, CO_2 equivalent, which measures the amount of carbon dioxide that would produce the same global warming potential as the total amount of greenhouse gases. In 2000, 77% of the global warming potential was from CO_2 emissions.

[13] The reference scenario assumes no policy changes relative to what we have now, a constant oil price and a stable GDP growth.

23. Emissions from land use and agriculture are also increasing due to livestock emissions, fertiliser application and continuing tropical deforestation. The scenarios developed by the IPCC, which take into account these non-energy related emissions, project an increase in global greenhouse gas emissions of between 63% and 235% by 2050 depending on the underlying assumptions[14].

24. Forecasting the path of emissions decades into the future is inherently difficult, not least because of the sensitivity of forecasts to factors such as GDP growth, population increase, technological change, and fossil fuel prices. There are debates, for example, about the likely degree of convergence of GDP per capita between developed and developing countries over the next century, about trends in greenhouse gas emissions per capita, and about what it is reasonable to assume about the introduction of new technologies.

25. But we can illustrate the general direction of estimates by looking at the growth rates of the key emerging economies, such as India and China. These countries have been maintaining rapid rates of growth in recent years – over 7% per annum; if they continue at these rates, their economies will double every ten years. There is no reason to believe that energy markets will by themselves bring about sharp drops in the carbon-intensity of energy usage without any policy intervention; estimates of fossil-fuel stocks – particularly of coal[15] - available at moderate marginal extraction costs suggest that they are easily sufficient to generate the emissions projected in fossil-fuel-intensive scenarios.[16] For example IEA's World Energy Outlook 2004 forecast that global emissions of CO_2 from coal fired power generation would increase by about 70% by 2030, and transport emissions by nearly 80%.

26. So whilst the exact path for future emissions will depend on many factors, the overall trends are clear. Emissions of greenhouse gases will continue to rise for some time, and at current rates of growth without concerted policy action to contain them, we are likely to see at least a doubling of concentrations relative to pre-industrial levels by the middle of this century. And whilst most of the emissions have come from the small fraction of the global population that is relatively rich, future growth in emissions will be dominated by developing countries.

27. Stabilisation will require significant reductions in emissions of greenhouse gases even compared to global levels in 1990, and the scale of the effort required is much larger compared to business-as-usual scenarios for global economic growth (Figure 1.5). As advances in science continue to bring the climate change issue into sharper focus, the implications of different stabilisation levels will need to be examined carefully, both in terms of their effects and their achievability.

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[14] Source: WRI (2005) Navigating the numbers http://climate.wri.org/navigatingnumbers-pub-4093.html

[15] At current rates there are sufficient proven coal reserves to last 200 years (IEA World Energy Outlook 2004)

[16] Scenarios such as the IPCC SRES A1FI

Figure 1.5. *Two example sets of global emissions pathways to achieve different target stabilisation levels. Note: These only represent two possible pathways to achieve stabilisation. Grey shaded rows show stabilisation pathways with approximately equal CO_2 concentration.*

Scenario Name	Final Stabilised Concentration of CO_2 only	Global Emissions Pathway		
		Year When Global Emissions Fall below 1990 levels	Change in Global Emissions in 2050 relative to 1990 levels	Change in Global Emissions in 2050 relative to business-as-usual*
IPCC 2001 Stabilisation Scenarios: CO_2 only				
450ppm CO_2	450	2000 – 2040	-5% to –60%	-60% to –85%
550ppm CO_2	550	2030 – 2100	-10% to +70%	-30% to –65%
650ppm CO_2	650	2055 – 2145	+10% to +110%	-15% to –55%
2005 Stabilisation Scenarios: all major greenhouse gases included, and expressed as CO_2 equivalent (CO_2e)				
400ppm CO_2e	350 - 375	2020 - 2030	-40% to -55%	-75% to -85%
450ppm CO_2e	400 - 420	2030 - 2040	-15% to -40%	-65% to -75%
500ppm CO_2e	440 - 460	2035 - 2055	Up to -25%	-60% to -70%
550ppm CO_2e	475 - 500	2045 - 2065	-10% to +10%	-50% to -60%

*Business-as-usual is represented by the IPCC A2 Scenario

Source: Based on IPCC (2001) and den Elzen and Meinhausen (2005). Assumptions underpinning calculations are explained in detail in Figure A4 in the Technical Annex.

Likely impacts of climate change on people and livelihoods

28. There are strong global and regional effects of climate change that are predicted consistently across most climate models and that will have major impacts on lives and livelihoods. For example, climate change is very likely to cause major water shortages for hundreds of millions of people in Asia and South America whose dry-season supplies come from melting snow and glaciers[17]. In many parts of world, glaciers are melting at an unprecedented rate. In Peru glacial coverage has fallen by 25% in the past 30 years. In China, virtually all glaciers have already shown substantial melting, with implications for almost one-quarter of the country's population that rely on glacial melt for summer water supply. Accelerated melting of glaciers could lead to flooding in the spring if the melt takes place too rapidly, followed by water shortages in the summer from a depleted stock.

29. We can also expect to see changes in the Indian monsoon, which could have a huge impact on the lives of hundreds of millions of people in India, Pakistan and Bangladesh. Most climate models suggest that the monsoon will change, although there is still uncertainty about exactly how. Nevertheless, small changes in the monsoon could have a huge impact. Today, a fluctuation of just 10% in either direction from average monsoon rainfall is known to cause either severe flooding or drought. A weak summer monsoon, for example, can lead to poor harvests and food shortages among the rural population – two-thirds of India's

[17] Barnett TP, Adam JC, Lettenmaier DP (Nov 2005) Potential impacts of a warming climate on water availability in snow-dominated regions, *Nature* **438**:303-309

almost 1.1 billion people. Heavier-than-usual monsoon downpours can also have devastating consequences, as the flooding in Mumbai showed last year when more than 500 people perished.

30. Impacts will be uneven throughout the world. Some of the earliest and most severe impacts will be felt in vulnerable regions – particularly the developing world and sensitive ecosystems, such as the Arctic and coral reefs. Modern society is potentially quite vulnerable. Three-quarters of people in the world live within 80 km of a coast, and almost half of the world's cities with populations of over 1 million people are sited in coastal estuaries.

31. Climate change will affect those in the poorest countries who are least able to adapt to the changes or for whom the human toll of adaptation is great. Africa is likely to be particularly severely affected. Some estimates indicate likely falls of agriculture yields in Africa of up to 12% by 2080, potentially increasing the number of people at risk of hunger by tens of millions.[18] Work in this area is in its early stages and it is possible that the numbers could be much larger for some parts of the region. The continent is already highly vulnerable to extreme weather. In 2000, torrential rainfall led to the worst flooding to affect Mozambique in 50 years, killing 800 people and displacing almost 1.5 million people (12% of the nation's population).

32. Here in the UK we will not be immune. We will experience greater coastal flooding, water shortage (particularly in the South East), and heatwaves.[19] Temperatures experienced during the European heatwave of 2003 could be commonplace by the middle of the century and unusually cool by the end of the century.[20]

Key questions for the Stern Review

33. The science of climate change raises central questions for policymakers.

34. The Stern Review will explore these questions, including:

- What are the economic and social implications for people in different countries and regions of a range of possible climate change outcomes, including in terms of incomes, lives and vulnerabilities?
- How should we tackle the problem of forecasting future emissions growth, and what is the range and likelihood of possibilities under different assumptions?
- How should policymakers understand and respond to the predicted increased risk of extreme events and major irreversible changes?
- What do we know about the possibilities for, and constraints to, adaptation to climate change?
- More generally, how can the world act in a coherent and collaborative way to tackle a problem that is global in its origins and effects?

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[18] Parry M, Rosenzweig C, Iglesias A, *et al.* (1999) Climate change and world food security: a new assessment, *Global Environmental Change* **9**: S51 – S67

[19] UK Climate Impacts Programme (April 2004) Climate change scenarios for the United Kingdom, http://www.ukcip.org.uk/scenarios

[20] Hadley Centre (2004) Uncertainty, risk and dangerous climate change, http://www.metoffice.com/research/hadleycentre/pubs/brochures/B2004/global.pdf

35. Much of the rest of this paper is devoted to developing and deepening these and related questions and, where possible, highlighting relevant analytical directions.

36. We will also highlight areas where science could go further to inform economic policymakers, including:

- Greater understanding of the probabilities of different ranges of outcomes and of major irreversible changes.
- Information on regional impacts to assist with better infrastructure design and the ability to manage water stress in developing countries and adaptation (and avoidance of maladaptation) more generally.
- Understanding of the environmental and climate consequences of strategies to reduce greenhouse gases, such as greater reliance on different types of fuels, methods of electricity generation, or modes of transport.

Section 1.2: What has been the international response to climate change?

37. Whilst the key insights into the science of greenhouse gases are more than a century old, understanding of the potential scale of human-induced climate change began to develop in the 1970s. Climate change has been recognised as a global problem requiring an international response since the 1980s.

38. The international community has created a number of institutions to help us understand and manage our response. The first of these institutions was the Intergovernmental Panel on Climate Change, set up in 1988 to review available scientific information.

39. This led to the negotiation of the UN Framework Convention on Climate Change, signed at the Earth Summit in Rio de Janeiro in 1992. This established the objective of the "stabilisation of greenhouse gases in the atmosphere at levels which would prevent dangerous anthropogenic interference with the climate system, in a timeframe that allows ecosystems to adapt naturally, food security to be preserved and economic development to proceed in a sustainable manner".[21] The Convention called on developed country parties to stabilise their emissions of greenhouse gases in the year 2000 at 1990 levels, and set out a framework for international action based on a number of key principles: equity, and common but differentiated responsibilities for all countries according to their capacity to respond; a precautionary approach, such that "where there are risks of serious and irreversible damage, a lack of full scientific certainty should not justify postponing action"; and a recognition that measures to control climate change should be cost-effective.

40. Further negotiations led in 1997 to the creation of the Kyoto Protocol, which took the first steps towards translating this framework into specific action, including by setting targets for developed country emissions reductions amounting to an overall 5% cut from 1990 levels by 2012, creating flexible mechanisms to reduce the costs of meeting the targets, and providing a basis for assessing and funding work in adaptation. The Kyoto Protocol came into force in 2005, with support from 130 countries (but without the participation of two of the major developed countries, the USA and Australia).

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[21] Article 2 of the UN Framework Convention on Climate Change – see page 9 of: http://unfccc.int/resource/docs/convkp/conveng.pdf

41. The flexible mechanisms in the Kyoto Protocol include the use of international emissions trading to reduce greenhouse gases, "Joint Implementation" to promote collaboration between developed countries, and the creation of the "Clean Development Mechanism" to allow developed countries to gain credits for investing in greenhouse gas reductions in developing countries.

42. Alongside this global framework, the European Union and some other countries and regions have launched mandatory and voluntary Emissions Trading Schemes for greenhouse gases. Trading between the 25 EU member states began by establishing a first phase from 2005-2007, a second phase from 2008-2012, and provision in EU law for further phases beyond this. Seven northeastern states of the USA are participating in a voluntary scheme, the Regional Greenhouse Gas Initiative, which was launched in late 2005.

43. Another key area of international action has focused on technology cooperation. The International Energy Agency has a range of programmes designed to help countries to share expertise on energy technologies. There are now a wide range of technology partnerships, including those promoting specific technologies such as those for renewable energy sources and carbon sequestration, and the newly launched Asia Pacific Partnership on Climate Change and Clean Development. Leaders at the G8 Summit at Gleneagles in July 2005 recognised the importance of using existing technologies and promoting innovation to tackle climate change, and created an Action Plan on Climate Change, Clean Energy and Sustainable Development. The Action Plan includes the creation of an Energy Investment Framework, led by the World Bank and other Regional Development Banks, to promote investment in lower-carbon energy infrastructure and in adaptation issues in developing countries.

44. Together, the existing institutions provide a strong basis for developing an effective collective response to climate change. And there is undisputed recognition of the need for a dialogue on how to move forward.

45. The Montreal Climate Conference in December 2005 (the 11th Conference of the Parties to the UN FCCC and also the 1st Meeting of the Parties to the Kyoto Protocol) saw the start of a twin-track. The Kyoto Protocol process will consider further commitments (i.e. emission reduction targets) for developed countries post 2012 and the Convention Dialogue aims to explore the basis for future action under the Convention in terms, for example, of the development of global carbon markets, the use of technology, adaptation, and the context of sustainable development. The Gleneagles Dialogue on Climate Change, Clean Energy and Sustainable Development launched at the G8 Summit in 2005 also provides a forum for countries with significant energy demand to consider the challenges of working towards a low-carbon economy.

46. The actions of individual countries, states, cities, companies and individuals will also be critical. There is already a wealth of evidence about how responses at these levels have been successful in reducing emissions at low or even negative economic cost.[22] Effective action requires efforts at all levels.

[22] For case studies, see for instance http://www.theclimategroup.org

Section 1.3: From the science to the economics

47. Climate change, in common with other environmental problems, embodies an externality: the emission of GHGs imposes a cost on others that is not borne by the emitter. So without policy intervention the emitter does not consider this in their decision making. But these costs are felt over a long period and over the entire globe, and their exact nature is uncertain. These and other complexities imply that the application of the theory of externalities, in simple standard form, poses many problems and questions.

48. The standard textbook theory assumes certainty, with no other externalities or market failures, and a single government in the community in question that represents all those involved. However, in the case of climate change we have uncertainty, interactions with other externalities and other market imperfections, global involvement, and weak representation of those most affected (future generations). Thus we have instead a complex inter-temporal international collective action problem under uncertainty.

49. This dictates the structure of the relevant economics. It is clear it must cover a very broad range including the economics of: growth and development; industry; innovation and technological change; institutions; the international economy; demography and migration; public finance; information and uncertainty; and environmental and public economics generally.

50. Given the global nature of the problem, we will need to use economic tools such as game theory to understand how players with very different incentives, preferences and cost structures will interact and can reach agreement. Getting a constructive agreement will require not only a shared understanding of the issues and mechanisms but also careful attention to the complex equity and other ethical issues involved.

51. In their interactions, international participants are likely to want to take into account a number of ethical perspectives, including consequentialism, equity, fairness, justice, freedom, rights-based approaches, sustainability and stewardship. Whilst these perspectives have some fundamental ethical differences, and may suggest different actions or processes, their application would, nevertheless, generally point to a focus on similar measurable outcomes such as incomes, forms of capital and wealth, health, way of life and so on. And in seeking international agreement, there would be clear advantages in finding actions and processes which would look attractive relative to many of these perspectives.

52. Climate change is not amenable to simple fixes. Our response to climate change concerns the choices we make about development, growth, the kind of environment and society we want to live in, and the opportunities it affords this and future generations.

Part Two: Key challenges for the economics of climate change

53. Part Two highlights the issues that will form the key elements of the analytical foundation for our examination of the economics of climate change. These issues follow from the logic of the scientific foundations presented in Part One: above all the science dictates that this is a problem which is global in its origins and impacts so that any effective response requires global collective action. In analysing the issue in this way, we build on the basis in international action established over the past two decades. The analysis also builds on the foundations of previous work in economics.

54. The economics of climate change hitherto has been focussed on modelling the implications of growth for emissions, examining and modelling the economics of technological options, calculating 'social costs of carbon', and exploring tax, market and other structures. Many elements of the foundations have been established.

55. We now, from the essential perspective of the international collective action problem, must focus on:
    - The analysis that individual countries will need to assess their own policy position.
    - An analysis of how to generate strong international action.

56. We will focus on developing ideas in key areas that, in our judgement, have been under-emphasised in the body of economic work currently available.

57. On this basis the analysis in Part Two is structured as follows.

    - First, we discuss the potential consequences for growth and development in both rich and poor countries of different paths of climate change. This is generally characterised as the issue of *adaptation*.
    - Second, we examine the potential for action to reduce greenhouse gas emissions in different regions and sectors. This is generally characterised as the issue of *mitigation.* We pay particular attention both to potential areas for action and implication for costs, competitiveness and growth.
    - Third, we highlight the way in which *uncertainties* and irreversibilities permeate the story.

Section 2.1: The impacts of climate change on growth and development

58. Climate change has profound implications for the environment in which social and economic activity takes place, and therefore has the potential to have significant effects on prosperity and human development. We need to understand how growth, in broad terms, and indeed other indicators of human development may be affected by the changes in the environment that will occur in the absence of GHG control. Whilst the balance of the evidence suggests the impacts will be negative it is important to recognise and incorporate any benefits from climate change.

59. The potential implications for economic growth and competitiveness of action to reduce greenhouse gas emissions are also important, and are considered below in Section 2.2.

60. One of the principal ways in which economic analysis has tried to quantify the impacts of climate change has been through integrated assessment modelling, which tries to capture the essential links between greenhouse gas emissions, climate change, and its impacts on the economy and society. These models have generated many important insights, most notably into the year-on-year impacts of climate change on market sectors of the economy such as agriculture. Yet there are often important omissions, such as many impacts outside the market sectors of the economy. Another issue deserving of more attention is the macroeconomic consequences of climate change, which can feed through to the long-run growth and development of the economy.

61. There are several channels through which the beneficial or harmful impacts of climate change may have macroeconomic consequences:

- The direct effect on the output – for instance, when, because of a deteriorating environment, agricultural productivity is reduced. In the short run, this will tend to reduce the output obtainable from each additional unit of physical capital and therefore, unless there is an offsetting increase in the rates of saving and investment; a deteriorating environment corresponds to a lower rate of growth than a stable environment;
- Increased depreciation of capital, because of both direct impacts from climate change (e.g. because of the need to replace sea defences) and accelerated economic obsolescence due to the need to change technologies at intervals to suit the changing climate (e.g. switching from heating installations to air conditioning);
- Adverse effects through the impact on people's skills and health, especially in poor communities, so that a given rate of population growth is associated with lower GDP growth;[23]

62. More speculatively, more severe climate change could affect economy-wide productivity, if its ability to assimilate new techniques, contribute to innovative research and import and adapt new technologies were impaired. That is not inconceivable, especially in countries already suffering low growth and whose technological capabilities remain behind the world leaders.

[23] Gallup, J.L, J.D. Sachs and A. Mellinger (1999). Geography and Economic Development. CID Working Paper 1. Cambridge, MA: Harvard Center for International Development.

63. Over the longer term, the consequences for growth rates will depend on how saving rates, investment rates in different types of skills, knowledge and physical capital, rates of capital depreciation and population growth rates react. There is as yet little detailed empirical evidence about how these factors would play out.[24] However, it seems likely that empirical measures of growth would be adversely affected, the more so as the effects of climate change accumulate.

64. There are historical precedents for the harmful impacts of pronounced climate change. Economic geographers and historians have drawn attention to the pervasive impact of climate on economies and societies, for example in aggravating the decline of civilizations including in ancient Sumeria (modern Iraq) and Central America (i.e. the Mayans).[25]

65. Developing countries are likely to be the worst affected by climate change. They will be hit not only by increasing variability (for example suffering potentially a greater incidence of both drought and flood) but also by a more adverse overall environment as temperatures, and sea levels, rise. They will have to deal with this in the context of low income levels and existing stresses (e.g. high population growth, high disease burden, land degradation and increasing water stress), allowing slim margins for adjustment. This combination presents a very serious challenge.

66. Adaptation has the potential to reduce the impacts of climate change. Substantial climate change is already inevitable over the next 30 years – mitigation will have a limited effect on stocks of GHGs in this time frame – and thus promoting and managing adaptation is an essential policy response. However, adaptation can be complex – there are no unique solutions, costs can vary widely and many of the methods are still in their early stages of development. There are limits to, or sharply rising costs associated with, the ability to adapt to fundamental and rapid climate change, especially given that the specific changes in any particular locality are uncertain.

67. The concept of the social cost of carbon can be helpful in discussion of some aspects of policy. The social cost of carbon is the monetary value of worldwide damages caused by carbon emissions. More precisely, the social cost of carbon that economic policy-makers focus on is the present value of the worldwide damage caused by an additional tonne of carbon emitted to the atmosphere, throughout its lifetime in the atmosphere.

68. However, there are considerable uncertainties and difficulties inherent in the concept, calculation and application of the social cost of carbon – most notably difficult ethical choices on the valuation of impacts on future generations and on developing countries (in the latter case given the greater incidence of poverty in developing countries). And a single figure can be misleading – not least because we are not dealing with a single jurisdiction. However, the large amount of useful information produced in the search for a social cost of carbon can be unpacked and form a key part of the analysis of the consequence of extra carbon for different regions of the world at different times in the future.

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[24] Largely conceptual contributions include Sinclair, P. (1994). 'On the optimum trend of fossil fuel taxation'. Oxford Economic Papers. **46**: 869:877, and Kelly, D. and C.D. Kolstad (2001). 'Malthus and climate change: betting on a stable population'. Journal of Environmental Economics and Management. **41(**1): 135–161.

[25] Fagan, B. (2004). The Long Summer: How Climate Changed Civilization. London: Granta.

Key questions for the Stern Review

- What is the potential impact of climate change, including both impacts of multiple extreme weather events and adverse impacts on the overall environment, on paths and patterns of growth and development in richer and poorer countries?

- How are integrated assessment models (discussed in paragraph 60)[26] used to arrive at estimates of the damage of climate change and how could the combination of economic, social and scientific aspects be improved in modelling?

- What is the potential for adaptation to changes in the climate, and how might this vary by country and region?

- What are the roles of equity weighting and discount rates in estimates of the 'social cost of carbon'? And are approaches both to intergenerational equity and discounting likely to vary strongly across countries?

Section 2.2: Taking action to mitigate climate change

69. Climate change is driven by greenhouse gas emissions from energy use, agriculture and deforestation. Mitigation measures should consider the possibilities for reductions in all sectors, including the potential to make cuts in GHGs from agriculture and land-use changes, which account for a very significant proportion of global emissions. But with energy currently accounting for around two-thirds of emissions and growing rapidly, much of the economic analysis to date has focused on this.

70. Reductions in energy-related emissions depend largely on breaking the links from economic activity to energy intensity (that is, using energy more efficiently), and from energy intensity to carbon intensity (that is, reducing the carbon content of energy). Energy conservation and efficiency have an important part to play, as does the development and deployment of low-carbon technologies.

71. We must ask how quickly current patterns of energy production and use can or should be shifted, and whether this can be done in a way that strengthens, rather than weakens, economic growth. Strengthening of growth can arise if the new approaches lead to a shake-out of inefficiencies and a burst of creative activity.

72. Assessments of mitigation actions should consider not just the global picture, but also how different regions and countries are likely to be influenced by the range of options for addressing GHG emissions. For example, a country with a large coal endowment may be more likely (given transport costs) to focus on coal-fired power stations.

73. The simple theory of externalities would point towards one of three basic approaches for designing policy to achieve emissions reductions: taxation on the emitter equivalent to marginal external social cost;[27] the allocation of property

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[26] Integrated Assessment models attempt to quantify the channels through which climate change affects the economy.
[27] As described by Pigou: Pigou, A.C., (1920), *The Economics of Welfare,* Macmillan, London

rights in conjunction with trading;[28] and direct regulation. To be effective, these should be reinforced by institutions which can sustain and enforce action over time; and persuasion, discussion and information aimed at changing preferences and behaviour.

74. Different policy approaches have different distributional and public finance implications. Regulation, for instance, tends to place the burden on industry (which is generally passed through to the consumer). Taxation (ultimately borne by households) raises revenues, which can then be used to achieve other goals; it also provides incentives – as does appropriate trading – to economise on the activity causing damage.

75. Assigning property rights to emitters, and then allowing these to be traded – the basis of emissions trading – works by providing large emissions sources with the flexibility to trade in emissions rights across different sectors. In equilibrium the price at which the reductions are made is equal to the lowest long-run abatement cost option that firms in the scheme can adopt to reduce emissions.

76. However, as already noted, climate change has characteristics including uncertainty, irreversibility and the need for a global response. These make policy design far more complex than simple theory might suggest.

77. Policies are also, in practice, designed with multiple objectives in mind. As well as the direct impact on greenhouse gas emissions, policies may also have a secondary impact on the incentives to develop new technologies, which will ultimately reduce the costs of cutting emissions.

78. At the national level, governments are likely to be concerned with the potential adjustment costs of moving towards a low carbon economy, including the impacts on the competitiveness of particular industries and the overall economy.

79. Climate change policy also needs to be set alongside other important energy policy priorities, such as security of supply and, in developing countries, access to energy.

80. And the effectiveness of policies depends very much on the context into which they are introduced. Global energy generation markets, in particular, are highly complex. Market structures in generation are often imperfect, so that the incidence of and response to different policy measures are not easily predicted. Energy markets are also characterised by volatile fuel input prices, complex regulatory regimes, and high-cost, long-lived investments. The price of fossil fuels are likely to include a component of rent reflecting their exhaustibility, complicating price dynamics further.

81. The various complicating factors may well pull in different directions. This tends to suggest that no one policy instrument is likely to be sufficient. A combination will be needed, and different countries will have different approaches depending on their own priorities and circumstances. At the same time, management of the issues of growth, pace of adjustment, and competitiveness is likely to be more successful if groups of countries act together so that their economies adjust to changes in relative prices over a similar time period.

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[28] Based on the theory of property rights described by Coase: Coase, R.H., (1960), 'The Problem of Social Cost.' *Journal of Law and Economics* 3: 1-44.

82. It is also clear that if the private sector is to deliver the changes needed to achieve a stable climate, clear, long-term and credible signals will be needed to guide its decisions.

83. For all countries, understanding the costs of mitigation will be critical. Existing estimates vary considerably. One important factor in the variation of these estimates is the assumption made about the nature of technological progress, specifically whether innovation can be stimulated by policy. If policies to reduce emissions are assumed to accelerate the development of these technologies, then the costs of mitigation will look much lower than if technological development is assumed to happen exogenously.

84. Financing the transition will be particularly challenging for developing countries. For this reason, they are likely to seek external finance for the investments involved in their contribution to mitigation. The magnitude of the challenge and limits to overseas aid indicate that scaling up market mechanisms, such as emissions trading and the Clean Development Mechanism, for promoting such investments is likely to play a crucial role. Examination of the role of rights to technology will also be an important issue.

Key questions for the Stern Review

- How can action be taken to make deep cuts in greenhouse gas emissions without a significant reduction in the rate of growth and competitiveness? Can innovation and technological change help us to move to higher growth paths?
- How far can land use change and forestry play a part in mitigating climate change?
- How can policymakers create sufficiently clear and credible signals and the institutions to support them?
- What is the role of persuasion and education to change preferences?
- How might these policies interact with existing incentives embedded in complex markets, particularly those for fossil fuels and electricity generation and supply?
- What are the market barriers and failures that may prevent the development and deployment of new and existing low carbon technologies, and what are the appropriate policy instruments to overcome these?
- What are the distributional and revenue effects of different combinations of policy instruments?
- What is the scale of investment required internationally and in developing countries, and what policy arrangements including economic instruments and flexible mechanisms could promote appropriate flows?

Section 2.3: Dealing with uncertainties and irreversibilities

85. There is uncertainty about many aspects of the economics of climate change: about prospective emissions, their impact on climate, the effect of climate change on societies and economies, and the feedback from both climate change and mitigation to growth.

86. This uncertainty does not warrant inaction. In fact, the significant possibility of severe adverse consequences of climate change may justify more extensive action now on prudential grounds than would be suggested by scenarios based

only on a central estimate of impacts, which do not take into account the potential severity of the downside risks.

87. The existence and nature of uncertainty can have a profound effect on the choice of policy instruments for mitigation, particularly the role of taxes, markets and regulation. Key factors include the costs associated with reaching thresholds that trigger irreversible impacts. A serious risk of adverse outcomes beyond a certain level might point to the use of policy instruments which control the quantity of emissions directly, and so give greater certainty over the volume of reductions. The downside is that costs may be higher than from more market-orientated mechanisms.

88. Such uncertainties are also central to how we evaluate future costs and benefits against costs and benefits today. Discounting is a key challenge in climate change policy, because many impacts will occur in the far-off future. How we approach discounting under uncertainty can be rooted in the fundamental principles of welfare economics and cost-benefit analysis (pioneered by James Meade and Paul Samuelson among others). These tell us that the value we place on the marginal benefits of climate change action depends on the circumstances – the state of the world – in which they accrue and to whom they accrue.

89. In general, we would value an extra unit of income higher the less income we have. Assuming we will be richer in the future, this is the main reason why benefits in the future are discounted compared with benefits today. Yet where uncertainty about future income is high, the value of an extra benefit should be averaged across all possible outcomes, favourable and unfavourable. Accepting that we value extra income more the less we have, this explains why we should attach particular weight in decision-making to the worst potential outcomes of climate change.

90. Climate change is also characterised by irreversibilities. The very long duration of many greenhouse gases in the atmosphere means that our current and past actions have committed us to a particular trajectory of future temperature and climate changes which can now only be undone over a very long period. As noted above, future rises in temperature may commit us to physical processes that are irreversible, for example the melting of the Greenland ice sheet, and loss of important natural systems, including the Amazon rainforest.

91. Similar arguments also apply to investment in expensive capital stock. Power stations and aircraft, for instance, last for many decades; housing often for a century or more. The costs of prematurely retiring capital are usually high. Investments made over the coming years, therefore, will set us on a particular emissions pathway for decades to come. We need to understand what the key periods for large-scale investment are and how these may be influenced – examples include the massive investment in power generation expected in China and India over the next 10-20 years, and the replacement of capital stock in the power sector of many OECD countries over the same timeframe.

92. There is a risk of making irreversible investments in plant and equipment necessary for mitigating climate change that turn out to be unwarranted. But near-irreversibilities suggest an extra argument for taking more determined action now: There is an option value to reducing emissions while we learn more about climate change.

Key questions for the Stern Review

- How should one assess the degree of uncertainty about aspects of climate change?
- How can discounting be used to value costs and benefits into the future in the presence of uncertainty?
- What are the implications of uncertainty, and of the possibility of very harmful outcomes, for policy-making?
- How should the presence of uncertainties and irreversibilities affect the analysis of the appropriate timing and scale of action?

Part Three: Creating and sustaining international collective action

93. A response to the challenge of climate change must, given the global nature of the problem, be based on international collective action. Building on the science, the economic analysis must, therefore, provide a shared understanding of the nature of the economic problems it generates, inform the international participants of the implications for them, and other parties, of different actions and arrangements, and find ways of sustaining a collaborative response to the challenge.

94. A response to climate change must encompass both adaptation and mitigation. Adaptation has tended to receive less attention to date, but we will have no choice but to develop effective and equitable policy responses to the climate change we cannot avoid.

95. Part Three will look at how to:

- Foster a shared global understanding of the consequences of climate change
- Create the conditions for sustained international collective action
- Act together to rise to the challenge of adaptation as well as mitigation

Section 3.1: Principles of international collective action

96. Climate change is a global problem in origins and effects. It requires an international response. The countries involved need to understand the consequences of different arrangements both for themselves, and also for others, if they are to make an informed judgement on how to participate. Agreement is fostered if the analytical basis of this judgement is shared amongst countries.

97. Action on externalities in the environment is difficult even in the face of localised problems, such as traffic congestion. For climate change, with its global scale, long time horizons and uncertainties, the challenges are much greater. We live in a world of tremendous variety. Different nations coming together to negotiate global climate change policy bring with them different ethical frameworks, political pressures, structures of benefits and costs, and types of incentives and institutions.

98. But past achievements in various areas, such as trade, international financial stability and environmental issues such as the protection of the ozone layer, suggest that progress is possible. The agreement at Montreal in December 2005 to begin talks on future action on climate change was a highly significant step forward.

99. International collective action, if it is to be effective and lasting, requires complementary understanding, actions and institutions. Our actions, including at an international level, reflect underlying preferences and values that evolve over time. As our understanding of the implications of climate change grows, we should expect these preferences to move towards recognition of the value of a stable climate and of the benefits of acting collectively to achieve it. Indeed, policy should encourage them to change. This collective response will need to be supported by appropriate institutional and incentive structures, and mechanisms that are capable of sustaining the response even as political or other circumstances change.

Section 3.2: Fostering a shared understanding of the consequences of climate change

100. Action requires an understanding of, and concern for, the implications of the problem in question. History shows us that people care about the environment they live in, but also that the assessment of its importance, their own attitude to perceived responsibilities and their willingness to pay depend on information, education and public discussion. Choices will also depend on income and costs. The same is true across nations. As understanding and discussion progresses, action at local, national and international levels tends to follow – examples include recycling of waste; smog in cities; lead in petrol; acid rain; and global action to stop further depletion of the ozone layer.

101. Creating a shared basis for understanding climate change and the range of sound and effective responses to it is a crucial part of creating and sustaining international collective action. All countries will need to understand the implications for them of adaptation to and mitigation of climate change in terms of their growth, competitiveness, security and the public finances. Countries will, and should, be concerned also about the implications for others. The UK is no exception.

102. Analysis of these implications must offer a clear and, where possible, quantitative understanding of the likely impacts on different countries, regions and generations arising from different courses of action. Whilst these issues are complex, some broad directions and 'orders of magnitude' are already emerging. It is important for this economic and social analysis to proceed side-by-side with the science.

Section 3.3: Creating the conditions for sustained international collective action

103. Each nation individually has an incentive to free-ride on the mitigation efforts of other nations, even though everyone could benefit from mitigation. We know from basic game theory that we have to promote a collaborative solution to games with free-rider problems – familiar from the classic illustration of the "prisoner's dilemma". Collective action in response to climate change creates a clear aggregate gain over free-riding, and the challenge is to ensure that these benefits are understood by all, and that there is an equitable basis for participation.

104. The collective response, to be effective, requires underpinning needs to be underpinned by institutions and incentives that attract the support of the major stakeholders. The UNFCCC, Kyoto Protocol and other international and national initiatives provide a strong basis for developing an effective collective response to climate change, but there are some significant challenges to address if we are to create and sustain action on an appropriate scale.

105. Given that developing countries are likely to account for much of the growth in emissions over the coming decades, it is essential that international agreements support action in these countries. Market mechanisms such as emissions trading via the Clean Development Mechanism, if scaled up, have the potential to provide flows of private capital to help increase the uptake of lower carbon technologies in these countries. There are other mechanisms which will also support the wider diffusion of clean technologies, including shared research and development, the adoption of international standards, and cooperation on the role of investment regimes and intellectual property rights.

106. It is also important to find ways to sustain agreements, given the impact of free riding on the willingness others to take action to mitigate climate change. These include the basic toolkits of international agreements: creating treaty obligations and mechanisms for verification and compliance. But these should be combined with, and buttressed by, other instruments and methods. Public debate on appropriate national and international attitudes to climate change, and the education of current and future generations will play a significant role. Climate change should become a central element in the whole set of international engagements, and understood in the context of the wider multilateral system of international collaborative behaviour from which we all gain. Technological progress can also be locked in through international product standards, investment in new infrastructure and changing industry and consumer expectations.

107. Within this overall global context, individual countries and regions can play an important role in promoting and fostering international cooperation. This can include taking a lead in developing policy frameworks for climate change and demonstrating cost-effective ways to reduce emissions. International political leadership based on sound analysis is likely to be crucial.

Section 3.4: Acting on both adaptation as well as mitigation

108. Adaptation and mitigation are not alternatives: climate change is happening and will continue to do so, and will require changes to the way we live and work. The likely scale and potential costs of adaptation point to a requirement for strong mitigation.

109. As we have already highlighted, the adverse impacts of climate change will be felt most acutely and soonest by poor people in developing countries, in particular in Africa, because of their geographical and climatic conditions, their high dependence on agriculture and the natural environment, the deficiencies in their infrastructure, and their limited capacity and lack of financial and technical resources to adapt.

110. An equitable international response to climate change must include not just action on mitigation, therefore, but also finding ways of working with the most vulnerable countries and regions to ensure their growth and poverty reduction goals are not compromised.

111. The challenges for the international response to adaptation are distinct from mitigation, and some aspects of them involve local action to respond to local impacts, even though the origins of the problem are global. Action to adapt to climate change should be seen in the context of our overall international responsibility to promote development and fight poverty as expressed, for example, in the Millennium Development Goals. Key issues for adaptation policy include:

- *Improving information* - Sound understanding of the expected local effects of climate change, particularly in the longer term, will play a central role in shaping adaptation action.
- *Costs* - Adaptation entails transitional costs and can require large upfront defensive investments (e.g. learning new methods and changing infrastructure).
- *Distributional effects* - Uptake of adaptation will depend on existing vulnerabilities and an individual's capacity (e.g. access to complementary inputs) and propensity to act that will vary within and between countries.
- *Awareness* - Adaptation decisions require awareness of alternatives and planning capacities by institutions and individuals.
- *Multiple actors* - Adaptation involves a wide array of public and private actors acting in response to observed climate and expected climate change; coordination can be both vital and difficult.

112. Thus responses to adaptation involve a number of different types of action, including: providing information through better climate observations and regional predictions; increasing the resilience and reducing the vulnerability of those most at risk; investing in infrastructure such as flood defences; insuring vulnerable groups, including by the use of innovative financial instruments; providing information to guide individual and national decision making; and improving arrangements for disaster preparedness and disaster recovery.

Key questions for the Stern Review

- How can the Review best illustrate how different frameworks for international action affect different parties?
- How can international arrangements, and in particular the incentives, institutions and scale they embody, be taken forward to respond to the magnitude of the challenge?
- How can government action and public discussion build a common understanding to help change preferences and strengthen prospects for collaboration?
- What is the role for action in a single country or region, such as the UK or EU, in promoting international collective action?
- How can the international community, including the private sector, support adaptation in the most vulnerable countries?