Framing the Economics of Climate Change:
an international perspective

Submission to the Stern Review on the Economics of Climate Change

Michael Grubb with
Jean-Charles Hourcade,* Ottmar Edenhofer,* Nebojska Nakicenovic*

This submission offers brief observations across the "four pillars" of the Stern Review into the economics of climate change, and seeks to address some high-level questions about the nature of the problem from an economic standpoint. Whilst our focus is on the economic issues, the inspiration for our analysis is also multidisciplinary, and draws upon extensive experience in both academic and policy debates. We present evidence on each of the first three pillars, and in the concluding section draw some implications and criteria that might be applied to the design of international regimes.

Annexes (submitted separately)

* For author affiliations see Annex I. This submission incorporates contributions and/or comments from these authors but the timescale of the submission did not make it possible for the lead author to establish whether co-authors agree with this final text in entirety. In addition, the material draws significantly upon the insights of a colleague from a fifth country, Professor Carlo Carraro from FEEM in Italy who was unable to comment on this submission in the time available. Professor Carraro and the indicated co-authors are instead invited to send directly to the Stern Review any caveats or supplementary material they wish to submit.

1. Global emissions and economic development

Stern Review Pillar 1: *Examine the evidence on the implications for energy demand and emissions of the prospects for economic growth over the coming decades, including the composition and energy intensity of growth in developed and developing countries.*

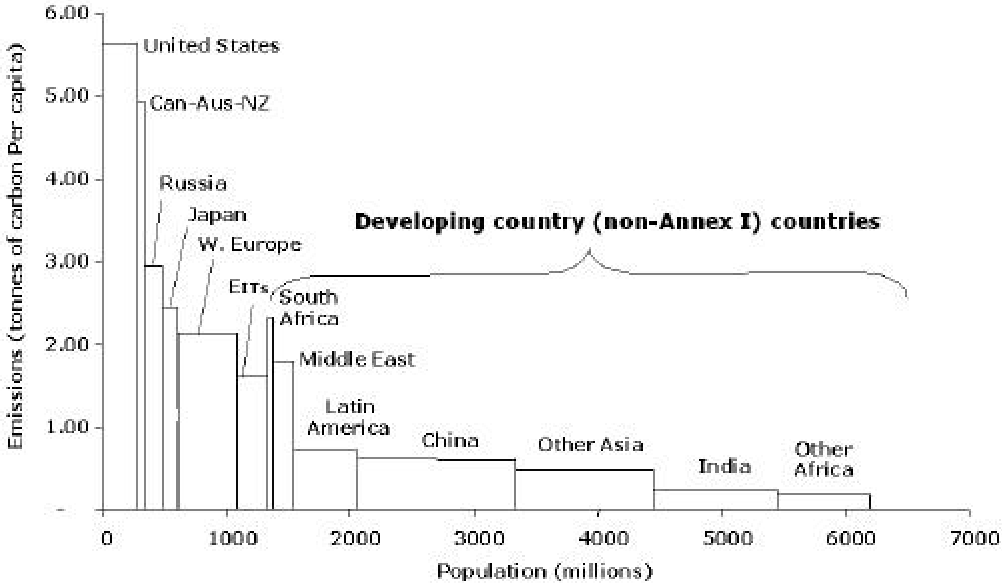

Figure 1. CO_2 emissions per capita and population by region in 2000
Source: Grubb (2004)

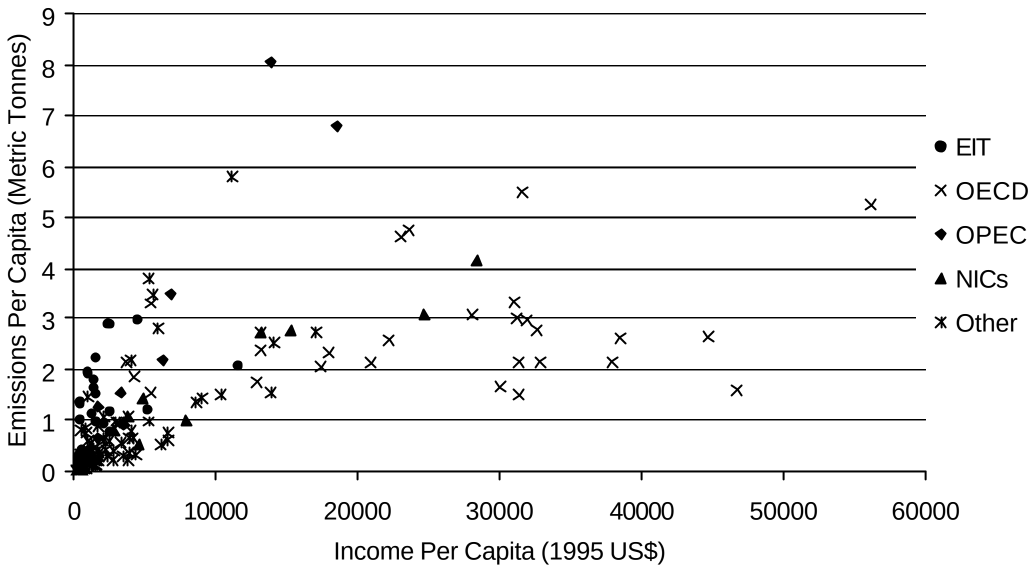

Figure 2. CO_2 emissions per capita for different economic categories as a function of income
Source: Grubb, Butler and Feldman (2005)

A useful starting point on Question 1 is a the present distribution of per-capita emissions and population by country / region (Figure 1), and correspondingly in relation to income (Figure 2). We combine these with wider economic debates to offer four specific points.

1.1 *There is huge potential for global emissions growth if countries pursue existing models of development.* The major drivers of change are population and economy.

Population. Recent debates have tended to lower populations projections for this Century, due to sharply declining birth rates, but most still involve projections that global population (the horizontal axis) will expand by around 50%: out of 115 population scenarios collated recently by IIASA for the IPCC (Lutz et al, 2001; UN 2005; World Bank 2005; US Census Bureau 2005), the majority project population in the second half of the Century to be moderately stable at around 9-10 billion people, and only one scenario involves global population declining below 5 billion by the end of the Century.

Economic growth and per-capita emissions. Recent debates about CO2-GDP relationships and projections have focused on metrics of measurement (PPP vs MER) and assumptions about economic convergence. Whilst the choice of GDP denominator would not be expected to have a *first order* impact on projections of a physical quantity such as emissions (Holtsmark and Alfsen, 2004a and b), it may have second-order impacts due to structural effects, inadequacies of PPP data and specific uncertainties. Nordhaus (2005) concludes that the 'jury is still out' and recommends a hybrid treatment using PPP base-year calibration with MER growth rates; Dixon (2005) presents evidence that PPP treatments could lower emission projections due to differential structural effects and associated sectoral emission intensities and elasticities. Overall the differences are generally modest compared to the overall impact of different growth assumptions, on which debate continues about expectations of economic convergence vs a continued bimodal distribution of world per-capita income levels (eg. Jones 1997; Quah 1993, 1996; Barro and Sal-i-Martin, 1997; Riahi 2005).

No country with income beyond c.US$10,000 per capita emits less than about 1.5tC/cap (Fig 2). This appears to reflect the emissions inherent in building basic industrial and urban infrastructures – a fact which if extrapolated forward, and comparing against Figure 1, implies considerable growth in developing country emissions on almost any scenario for the world economy (trends at higher incomes are considered below).

Since Figure 1 plots per-capita emissions against population, annual emissions are represented by the area of the blocks. With both expanding global population and rising per-capita emissions, the pressure for growth of obvious. The scenario ensembles from the peer-reviewed literature for the IPCC AR4 continue to find a very wide range of projected global emissions but the 'vast majority' of non-intervention scenarios result in global CO2 emissions in the range 15-25GtC/yr by 2100 (IPCC AR4 WG3 Ch.3 Fig 3.8).

1.2 Beyond the stage of basic industrialization, there are large differences in per-capita emissions and huge variability in the CO2-GDP relationship. This is evident from both Figs. 1 and 2. Per-capita CO2 emissions in the 'new world' developed economies, of 5-6tC/cap, tend to be around twice the levels typical in 'old world' economies, but the latter include a few rich OECD countries with emissions below 2tC/cap. This diversity is a modest source of hope, even based on current patterns: a world in which most countries by the end of the Century emit 1.5-2.5 tC/cap clearly has far lower climate risks than one in which they emit at up to 3 times those levels.

1.3 The biggest determinants of future emissions will be the combination of the patterns set by industrialized countries and the capacity of developing countries to 'leapfrog' towards higher-income but lower-emitting patterns of development.

We discuss specific issues surrounding the economics of mitigation below. Here we note wider issues around the relationship of emissions to development.

None of us are development economists, but we note that development economics has increasingly emphasized the scope of development choices and their dependence upon institutional capacity in developing countries (Meier, 2001). The same is likely to be true with respect to emissions, and since one impact of weak institutions is that economies operate further from the efficiency frontier it cannot *a priori* be concluded that stronger institutions and resulting higher economic growth will result in higher emissions. Higher dependence upon fossil fuels is not intrinsically good for development and carries numerous attendant problems ranging from other environmental impacts to exposure to international fossil fuel price variability. Institutional capacity to accelerate efficiency improvements and foster lower fossil fuel paths could put countries on pathways that are both lower emitting and better for development – the ideal being capacity to 'leapfrog' the inefficiencies displayed in traditional models of development (for extensive recent discussion see for example IPCC AR4 WG3 Chapter 12). However, as emphasized by a leading Chinese researcher (Zhou, 2005), it will be much harder for developing countries to achieve this unless the world's industrial powerhouses simultaneously develop the requisite lower-carbon technologies, businesses, capacities and institutional models.

1.4 In energy supply, these patterns will be set by how the world chooses to invest around $16trillion capital over the next few decades, investments that will have irreversible impacts throughout the century, but in which lower emitting infrastructure appears neither more costly in total nor more irreversible.

The uncertainties around global emissions growth trends, and the extent to which it depends upon choices made about the deployment of capital, are underlined by the IEA's World Energy Outlook (IEA, 2004), which estimates that about US$16tr will be invested in energy supplies up to 2030 (about US$10tr of this in the power sector), divided roughly equally between industrialised and developing countries. In their "reference" scenario most of the generation investments are in carbon-intensive stock; their "alternative" scenario involves more rapid growth in less carbon intensive investments, and although this is more expensive per unit, the scenario actually requires less capital investment overall because of the increased efficiency of end use (even when the end-use investments are included). The choice of path out to 2030 will have profound implications for the structure of capital stock, and its carbon intensity, well into the second half of this Century and even beyond.

Ulph (1997) noted that 'information acquisition and irreversibility could make a significant difference to policy advice', but models of irreversibility effects (Pindyck (2000), Kolstad (1996a and 1996b)) appear to have treated carbon and non-carbon intensive investments asymmetrically, assuming only the latter to be irreversible.[1] In practice both embody considerable inertia: every major investment is a decision with irreversible consequences. The dominant net irreversibility is then carbon in the atmosphere and associated damages. Uncertainty about impacts (relative to best estimate) consequently increase the attractiveness of low carbon paths, to a degree that depends on the potential damages, risks and degrees of irreversibility (see also section 3).

[1] 'Policy adoption involves a sunk cost associated with reduction in the entire emissions trajectory, whereas inaction .. only involves continued emissions over that interval' (Pindyck, 2000).

2. Evaluating climate change impacts

Stern Review Pillar 2: *Examine the evidence on the economic, social and environmental consequences of climate change in both developed and developing countries, taking into account the risks of increased climate volatility and major irreversible impacts, and the climatic interaction with other air pollutants, as well as possible actions to adapt to the changing climate and the costs associated with them.*

2.1 Structuring analysis and uncertainty about impacts

Evaluating the impacts of climate change from an economic perspective is fraught with difficulty. Continuing scientific uncertainties about the detailed nature, timing and severity of natural impacts are multiplied by many layers of uncertainty about how society will cope with growing impacts and how to quantify these. The impacts literature is dominated by natural scientists, economists have tended to concentrate on a few measurable dimensions that may not capture the most important effects. We attempt here merely to introduce some economic structure into the impacts debate, and draw some basic conclusions.

A separate submission by Downing *et al* to the Stern review has summarised the leading appraisal of the "social cost of carbon" (Downing et al., 2005). Table 1, drawn from this, helps to structure analaysis in terms of a 3x3 matrix covering the dimensions of uncertainty in both climate change impacts (rows) and the scope of evaluation (columns). As Downing et al note, over 95% of the studies that seek to put a monetized value on climate impacts have focused on only two out of the nine elements of the matrix. We accordingly structure our comments here into three dimensions: metrics of evaluation within the boundaries of existing comparative-static quantification studies; bounded risks and systemic change; and the dynamic and socially contingent issues that are barely represented in existing economic or scientific literatures.

		Uncertainty in valuation		
		A. Market	**B. Non-market**	**C. Socially contingent**
Uncertainty in Climate Change	**1. Projection**	Over 95% of the studies are in this category; with a bias toward market costs.		Plausible effects have been posed but not adequately valued nor included in the marginal SCC
	2. Bounded risks	Some models have explicit scenarios but most are tied to benchmark 2xCO_2 scenarios and do not cover local changes in weather.		
	3. System change and surprise	A few exploratory studies, but not sufficient to provide robust estimates of the marginal SCC		No credible studies

Table 1. Locating the 'social cost of carbon' literature in a risk assessment framework
Source: Downing et al. (2005).

2.2 Comparative static methodologies: discounting and contingent methodologies

The literature has clearly established that discounting over time is a critical determinant of the ‘present cost’ from impact assessments. The discounting literature is enormous, and appears to have led towards a consensus that market-oriented discount rates are not appropriate for evaluation of very long-term issues like climate change, culminating in the guidelines of the UK Treasury Green Book. This in itself has important implications, as sketched in the Downing et al report, establishing that the long-term cumulative impacts of climate change cannot be readily "discounted away" in evaluation of climate damages.

In the pursuit of treatments that are ethically consistent across space as well as time, similar scrutiny needs to be applied to the evaluation of transboundary impacts. Contingent valuation methodologies based upon 'willingness to pay' lead for example to valuation of mortality based upon national Value Of Statistical Life (VOSL), which is heavily constrained by national income and can differ by a factor of well over ten between countries – a fact which has already led to political dispute due to the apparent unequal valuation of life contingent upon the country impacted. In aggregate there is a huge 'North-South' asymmetry between the principal emitters and biggest potential victims: it is the rich countries whose mitigation expenditures would be most influenced according to the estimated global damages, not the poor.

Hence the case for using national VOSL (and other willingness-to-pay based measures) is unclear. A logical link can only be maintained by appeal to the argument that abatement expenditure in rich countries would displace foreign assistance for adaptation or other aid (an 'indirect opportunity cost' argument). But there is no evidence that mitigation expenditure does or would displace foreign aid. Moreover foreign adaptation assistance (partly due to institutional constraints and the dynamic uncertainties documented below) is likely to be an imperfect substitute for reduced climate variability.

Equity weightings attempt to correct for the inequities arising from willingness-to-pay approaches, but their derivation is unclear. We believe this reveals some genuinely complex ethical issues underpinning global aggregation of damages that have yet to be resolved. In the absence of any objective resolution, the only ethically defensible approach to global damage valuation must include input from negotiations based upon fair representation of both victims and emitters.

2.3 Beyond smooth change: bounded risks and surprise

In this submission we can add little concerning the impact of bounded risks and larger surprises, but emphasise that they are an important part of any comprehensive analysis. We assume that the Stern enquiry is familiar with the 'Burning Embers' diagram of the IPCC WGII Third Assessment report (WGII), which attempts to depict how different levels of atmospheric change may affect risk levels across five impact metrics. Scientific research since then has broadened understanding of some of the possible regional 'switch points' that may be subject to non-linear changes, as illustrated in Figure 3. The scale of threats posed by structural disruption, for example, to Indian monsoon or African rainfall patterns are extremely hard to evaluate, but clearly should not be ignored in any quantification that claims to be reasonably comprehensive. Of particular concern is how such impacts might interact with social capacity to adapt, which we now consider more closely.

2.4 Dynamic and socially contingent impacts

Whilst scientists grapple with trying to understand better the potential impact of climate change on extreme events and discontinuities (rows 2 and 3 of the risk matrix), we consider that the principal contribution of economists needs now to focus on understanding how a changing climate may impact societal welfare, and in particular, impact dynamics and the neglected 3rd column of the risk matrix - the socially contingent nature of impacts and their relationship to economic development. Key studies include those by Hourcade and his colleagues, as summarised in an appended presentation, that highlight several dimensions as follows.

Figure 3. Potentially sensitive "switch points" areas in which local effects might trigger larger-scale changes
Source: Schellnhuber and Held (2002)

(i) Transitional impacts. Spatial and time aggregation over the long run may mask the bulk of social costs, which are far more likely to be those associated with transitions and extremes: adaptation to a changed climate, predicted ex-ante, may be very different from adaptation to a changing climate, with attendant changes in the distribution and scale of extremes. Both theory and recent experiences (such as Asia and New Orleans) suggest that what matters is the joint effect of climate impacts and constraints upon preparation, reconstruction and adaptation capabilities.

Consequently the scale of losses may be sensitive to the pre-existing conditions of the economy on which climate change impacts may fall. Impacts may be aggravated by constraints on: (i) reconstruction capabilities; (ii) failure of cost-sharing mechanisms including insurance and international assistance; (iii) local obstacles including rigid agricultural practices; (iv) knock-on economic impacts arising from depreciation of this share of capital stocks (through real estate and property ownership); and (v) ecological constraints. Drawing in part on wider development literature on the economics of natural disasters (Benson and Clay, 2004)), Hallegate and Hourcade (2005) present a model in which poor societies are unable to recover from one extreme climate events before the next disaster strikes, leaving such countries trapped a cycle of under-development.

Moreover, inadequate mechanisms for adaptation, compensation and cost-sharing may lead to adverse effects propagating across regions (including through migration), blurring any distinction between 'winners' and 'losers'.

(ii) Uncertainty. The most obvious conclusion is that adaptive capacity needs greatly to be strengthened. This is unquestionably true but incomplete, not least because of the uncertain nature of impacts (particularly extremes) combined with the demonstrated incapacity of societies to prepare adequately on the basis of risk warnings (such as with the Asian Tsunami, and Hurricane Katrina). The *main* impact of climate change is likely to arise from the interplay between climate uncertainty and the various sources of inertia in social and economic systems.

Assuming that societies can adequately adapt to climate change neglects (i) that uncertainty in regional climate predictions is an order of magnitude greater than that in global average predictions, (ii) the masking effect of natural climate variability which means that climate change signals may be undetected, ignored or misinterpreted, and (ii) the capital-intensive nature and inertia of adaptation strategies (eg. dams, building norms, etc) entail a high risk of maladaptation. The first lesson from comparing 'optimal control' models is that costs and responses can be very different between perfect foresight and decision-making under high uncertainty.

(iii) Aggregation and the value of climate stability. Estimates of GDP losses associated with climate change in existing literature are thus questionable to the extent that they neglect issues of transition, uncertainty, and human capacity. When extrapolated to global estimates they also face questions about the ethical basis of aggregation indicated above, and moreover implicitly assume perfect compensation between winners and losers, which human institutions are unlikely to deliver.

Against this background, it is not hard to understand the conclusion of Downing et al. (2005) that the 'social cost of carbon' is characterised by huge uncertainties, spanning potentially from 1 to 1000£/tC.

Downing et al argue that the very low values in this range are unlikely, and we offer a complementary perspective that would have similar practical implications. The considerations set out above lead us to argue that from an economic standpoint, environmental quality and climate stability are themselves components in utility functions that should be explicitly represented: given loss aversion (one of the most stable findings in behavioural economics) there is an intrinsic value to avoiding an unstable climate because of the uncertainties inherent in climatic change. Moreover, although it is poorer societies that may suffer most from an unstable climate, the decreasing marginal utility of income means that high-income populations / generations should be more willing to spend resources on protecting the climate (in addition to the fact that they have been and remain the major emitters of greenhouse gases). Climate stability is thus a 'superior good' and this may also change significantly some of the policy insights, including those relating to the cost-effective distribution of mitigation investments.

2.5 Interaction of impact and emission paths

Most analyses of impacts have focused upon comparing different stabilisation levels. Far less attention has been paid to how different emission trajectories over the next few decades may affect climate impacts. O'Neill and Oppenheimer (2004) examine the implications of three types of pathways: 'rapid change' that follows 'reference' until at least 2030 before departing and stabilising in 2100; 'slow change' pathways that depart from 2005 and remain on a lower trajectory that finally reaches and stabilises at the target level in 2200; and 'overshoot pathways' that exceed the target level by 100ppm in 2100 and then decline to the target in 2100. For a range of different ultimate outcomes (target concentrations 500, 600 and 700ppm) they find that 'the range of temperature outcomes in 2100 across the three types [of pathway] … is about 0.5-1.2 deg.C, as large as or larger than the difference in long-term outcomes for different stabilisation levels.' Moreover, the 'slow change' pathways lead to median rates of temperature change that decline over time from an initial rate of 0.16deg.C/decade (for their central climate sensitivity), contrasting with peak rates of around 0.2deg.C/decade for the 'rapid change' 500ppm case, and approaching 0.3deg.C/decade for the 'rapid change' (and overshoot) scenarios with higher stabilisation levels. The authors conclude that the faster rates of change would both be harder to adapt to, and also would increase the risk of abrupt climate changes such as impacts on the Thermohaline circulation and polar ice melting.

These various factors suggest a strong evidence base that:

(a) climate change will result in significant social costs, adaptation is very important but cannot be expected to negate such costs;
(b) the risks associated with uncertainties and irreversibilities are considerable and also constrain the ability of adaptive measure to avoid adverse impacts: a stable climate is an intrinsic good, it is also a superior good so that rich societies bear the primary responsibility for moving toward this goal;
(c) delay in abatement will substantially magnify the costs and risks associated with climate impacts.

Against this background we now consider evidence on mitigation costs.

3. Costs of mitigation

Stern Review Pillar 3: *Examine the evidence on the costs and benefits of actions to reduce the net global balance of greenhouse gas emissions from energy use and other sources, including the role of land-use changes and forestry, taking into account the potential impact of technological advances on future costs.*

In section 1 we reviewed evidence that emissions are likely to grow substantially in the absence of policy interventions, though the rate of growth is quite uncertain and dependent upon numerous variables other than just CO2 abatement policy. We noted that within this span, lower emission paths are not necessarily more costly than higher paths, but no rich country has emissions below about c.1.5tC/cap and none have yet demonstrated a 'low carbon economy' to the degree that appears necessary. Moving towards this - and thus also demonstrating a viable model for low carbon development in developing countries - unquestionably hinges upon specific emissions mitigation policies, in addition to broader 'sustainable development' policies.

There is a huge literature on the costs and benefits of mitigation actions, and several reviews of this literature. Here we present evidence pertaining to three dimensions of energy-sector abatement: short-run action in relation to energy efficiency; sectoral and competitiveness impacts of economic instruments; and the conclusions from longer term global studies including technological change across energy systems.

3.1 Near-term implementation costs: analysis of evidence for the UK

Over the past year, the Carbon Trust has carried out an extensive evaluation of options for reforming and strengthening the UK Climate Change Programme (Carbon Trust, 2005), focusing upon energy use in business and commercial sectors. Part of the evidence base for the study involved mapping out sources of emissions and abatement opportunities. The latter consistently identified opportunities that appear cost-effective at a 15% rate of return (the “cost-effective” potential would be much higher at a public sector test rate of 3.5%). This is entirely consistent with the long-standing literature on the topic (eg. IPCC Third Assessment, WGIII; the report of the UK Performance Intelligence Unit which estimated the potential net value of energy savings to the UK economy at over £2bn/yr; and the Impact Evaluation of various government-sponsored progammes including the Carbon Trust's own programmes).

The Carbon Trust analysis for the CCPR categorised the barriers to uptake of cost-effective measures and the potential for policy to address them, concluding that potential remains for certain instruments to both reduce emissions and costs to the business sector.

"Bottom-up" modeling studies supported the UK Performance Intelligence Unit (2002) conclusions about the potential scale of savings available (which would be further enhanced in an era of rising fuel prices), and indicated that the strongest policy packages modeled could reduce business and public sector end-use emissions (not including supply-side fuel-switching) by about 1%/yr absolute - around 20% below baseline in 2020.

In addition the Carbon Trust employed two different macro-economic models. These two models estimated the GDP impacts of the strongest package to be +/- 0.3% in 2010. The Carbon Trust has already in its report and a separate submission (appended) indicated reasons for concluding that the real costs may lie somewhere mid-way between these, with actual GDP impacts negligible to slightly beneficial, and is conducting more detailed reconciliation studies. The high-level conclusion is that even in a relatively efficient economy like the UK, considerable scope remains for cost-effective abatement if the right tools are used – a mix of economic and 'bottom-up' instruments targeted to the barriers and drivers appropriate to particular sectors as mapped out in the Carbon Trust CCPR study. This provides important opportunities for embarking more strongly on the path towards a low carbon economy without economic risk.

3.2 Competitiveness impacts of economic instrum ents

Clearly no country will wish to put its economy at a significant competitive disadvantage through actions on climate change. Competitiveness is however a complex topic. The concept of "national competitiveness" is itself questionable, but the exposure of individual sectors is a topic of extensive political concern - though one in which rhetoric frequently eclipses quantified analysis. Amongst empirical and analytic studies, three broad conclusions appear directly relevant to policy formation:

- Extensive empirical studies of the relationship between environmental legislation and industrial relocation have failed to support to "pollution haven" hypotheses. A review by Sijm et al. (2004) concludes that "existing studies cannot provide a clear picture about the effect of environmental policy on the relocation of energy intensive industries; but they do indicate that - if a relation between environmental policy and relocation should exist - it is statistically weak." (p. 165). This – and the fact that only 10-20% of emissions from industrialized economies arise from internationally mobile energy-intensive industries - also sets a limit on substitution-based "carbon leakage" arising from actions in some industrialized countries.
- Modeling studies of the competitiveness effects of carbon prices, reviewed by Zhang and Baranzini (2004), provide some quantitative insights into why these effects are likely to be small. Baron and ECONEnergy (1997) conducted a static analysis of the cost increases from a $100/tC carbon tax across four energy-intensive sectors (iron and steel, other metals, paper and pulp, and chemicals), finding that cost increases are less than about 3% of all country-sectors studied. They conclude that "empirical studies on existing carbon/energy taxes seem to indicate that competitive losses are not significant" supporting the conclusions of the IPCC TAR, namely that "reported effects on international competitiveness are very small and that at the firm and sector level, given well-designed policies, there will not be a significant loss of competitiveness from tax-based policies to achieve targets similar to those of the Kyoto Protocol." (p. 589).
- Finally, sector market structure studies of the impact of the EU Emissions Trading System (OECD, 2005 and Carbon Trust, 2004) find that aluminium is the only sector whose profits decline; the Carbon Trust study indicates how much the different sectors

would need to raise product prices in order to maintain profits at pre-ETS levels, and finds that Cournot representation of market behaviour would lead to all sectors other than aluminium potentially profiting from the way that permit allocation interacts with pricing impacts. These studies do not rule out the possibility of individual sub-sectors or specific firms being adversely affected, but at the sector level, the general conclusions are that competitiveness concerns need not inhibit the use of economic instruments as currently being considered. More recent studies by the Carbon Trust (2005) extend the analysis to the cumulative impact of different policy instruments and separate EU from non-EU competition: whilst the modeling studies suggest that sectors other than aluminium continue to profit, the study does suggest that stronger action beyond 2012 may need to consider more carefully potential impacts on steel and cement in particular.

3.3 Global and long-term analyses of costs taking into account technological change

The feasibility, pace and cost of a technological transition towards sustainable energy use and production will be strongly influenced by the relative cost of higher and lower carbon emitting technologies. In particular at present, the cost of carbon-intensive supply sources are lower than many non-carbon supplies, and if this remains the case then the cost and difficulty of policy measures to drive a transition on to stabilisation trajectories will grow as the scales increase over time. Innovation is crucial. None dispute the potential role, value and importance of well-managed public R&D, and both the existence of and the qualitative implications of market-induced innovation for environmental policy are also widely accepted: Jaffe et al. (2004) note that 'both theory and empirical evidence suggest that the rate and direction of technological advance is influenced by market and regulatory incentive, and can be cost-effectively harnessed through the use of economic-incentive based policy. In the presence of weak or nonexistent environmental polices, investments in the development and diffusion of new environmentally beneficial technologies are very likely to be less than would be socially desirable.'

Quantification of the 'push' and 'pull' forces on innovation is complex and their relative influence remains in dispute. A simple illustrative study by Anderson and Cavendish (2001), reflecting technology diffusion on the basis of comparative cost with learning, suggests that introducing a carbon tax of US$100/tC would lead per capita emissions in developing countries to peak at just over twice current levels after about 40 years and then decline steadily. In common with studies by Nakicenovic and his co-authors (submitted separately to the Stern Review) they find that low-carbon futures are not necessarily more expensive in the long run, but would require different investment incentives over the next few decades, and the later the policy is introduced, the higher the peak emissions and the longer the carbon tax must be maintained to bring emissions down again to comparable levels. Grubb et al. (2002) also illustrate the potential global importance of induced technical change in terms of spillovers, if the adoption of Kyoto targets in the leading industrial powers and their subsequent expansion over subsequent rounds, combined with globalisation forces, would help to bring convergence of carbon emissions towards a common average level of emissions per unit GDP.

Even without explicit incorporation of technological change, internationalization of carbon price-related incentives could have a profound impact on future options. Shrestha et al. (2004) study three developing countries and illustrate how modest carbon incentives associated with the CDM (up to $US20/tCO2) could radically change the power sector capital structure over the next twenty years, and the subsequent capital endowment.

Against this background we draw attention to at least two major submissions to the Stern Review that include far more extensive analyses of the global costs of mitigation based upon modeling studies, namely:

(i) the joint submission of the Cambridge Centre for Climate Change Mitigation Research and the Imperial College Centre for Energy Policy and Technology, that includes meta-analysis of the existing literature as well as extensive discussion of issues relating to the role of innovation; and

(ii) the submission by Edenhofer et al., that presents results of global studies of the economics of atmospheric stabilization from the Innovation Modeling Comparison Project (IMCP).

We believe that these analyses establish beyond reasonable doubt two crucial insights:

- The costs of long-term deep CO2 emission reductions are uncertain but given appropriate policies can be bounded to a maximum of a few percent of GDP loss by mid-century. Obviously, the numbers involved are still potentially large in absolute terms – maybe tens of billions of dollars annually. It remains helpful to view these in context, as illustrated in Figure 4 which presents results from the ten models participating in the IMCP in terms of the relative impact on Gross World Product (GWP) over the century of emission constraints that lead to atmospheric stabilization at 550 and 450ppmCO2 respectively.
- In some circumstances costs can fall outside this range. The full range of models includes exceptions that illustrate both the economic risks associated with policies that are inadequate or too narrowly focused, and conversely, possible opportunities. The outlier that generates very high GDP losses (Hourcade, 2006) reflects a world with little foresight, with no early adjustment of policies relating to transport infrastructure and fuels, and which fails to develop low carbon transport options (nor does it represent possible land-use "offsets"). The result is that the world economy becomes trapped by constraints to which it no longer has the infrastructure and technological capacity to adapt in time, with severe economic repercussions.[2] At the opposite extreme, a global econometric model suggests that the additional energy sector investment and associated innovation driven by stabilization constraints acts to somewhat increase gross world product.

As illustrated, it is a correct and reasonable approximation to set stabilization costs in context by concluding that moving towards atmospheric stabilization at levels in the range 450-550ppmCO2 is unlikely to cost more than about one year's deferral of economic growth over the Century, providing that mitigation is carried out in a dynamically efficient manner that also helps to induce the development and international diffusion of improved low carbon technologies and industries (considered in the conclusions).

These analyses do not consider in depth the uncertainties and opportunities surrounding the natural carbon cycle and land use changes. Adverse trends in the natural carbon cycle, that reduce sinks and enhance emissions, may raise the stabilization levels above those implicit in the scenarios considered here. Conversely, mitigation options associated with land use change may offer additional opportunities for net abatement. These are beyond the scope of our submission, but should contribute in a comprehensive strategy.

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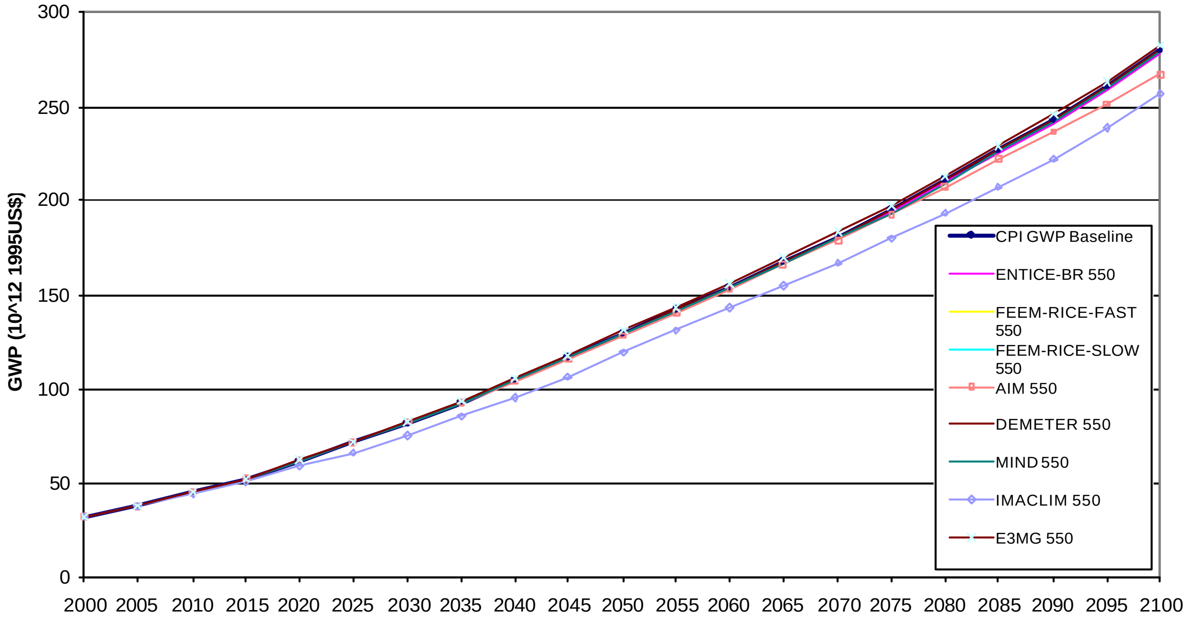
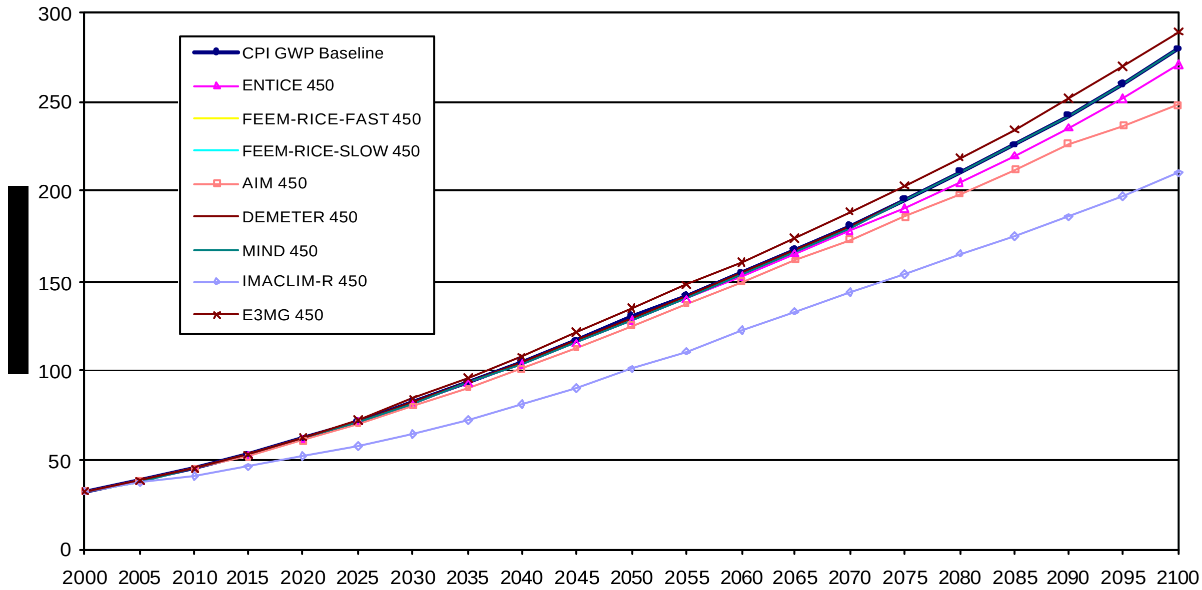
[2] Note that constraints on economically viable petroleum reserves could have a similar impact – highlighting the need to understand and reflect the interrelationship between oil resource and climate change issues, and of innovation in relation to both (Grubb (2001)).

Figure 4. Relative impact of CO2 stabilisation on Gross World Product

(a) Stabilisation at 550ppmCO2



(b) Stabilisation at 450ppmCO2



Source: Innovation modeling comparison project (Energy Journal, forthcoming 2006)

Note: The charts show GWP under the "Common Poles-Image" baseline, and the relative impacts of stabilization across the participating models. Different models have different absolute baselines.

4. Policy implications and conclusions

Stern Review Pillar 4: *Examine the evidence on the impact and effectiveness of national and international policies and arrangements in reducing net emissions in a cost-effective way and promoting a dynamic, equitable and sustainable global economy, including distributional effects and impacts on incentives for investment in cleaner technologies.*

This final section draws some conclusions from the analysis presented above and considers implications for responses, particularly relating to international mitigation regimes.

4.1 Methodology and assumptions: the nature of the challenge.

Many of the features considered above suggest characteristics of climate change that complicate economic assessment in several dimensions:

- the timescales are intergenerational, making any comprehensive assessment highly sensitive both to discounting assumptions and assumptions about the degree and processes of technological change;
- the impacts are transboundary and global, raising complex issues of equity in valuation and the regional, leakage and spillover issues in non-global or differentiated actions;
- the changes implicit in solutions are both non-marginal and carry multiple implications beyond their consequences for greenhouse gas emissions and climate impacts, meaning that assessments cannot rely purely upon marginal estimates and must factor in various co-benefits;
- and quantifications are dominated by uncertainties, path-dependencies, inertia and irreversibilities in both impacts and response measures.

Economic assessments can help effective policymaking to the extent that fundamental assumptions of economic theories are clarified with respect to these characteristics, and modified where necessary to ensure that economic tools are appropriate to the nature of the problem.

In particular, the intergenerational and transboundary nature of the problem implies that metrics for assessing optimal responses should be robust with respect to choice of generation and country; otherwise they will appear to be unethical and / or impractical as a basis for forging a coherent global response. Yet a single universal metric is probably unattainable. The pluralistic nature of ethical standards and metrics of fairness can be problematic, but may also offer opportunities to foster international cooperation: the unidimensional 'rational actor' paradigm is too pessimistic about the possibility of addressing public good problems because it underestimates the power of reputation, interest in fairness, and the importance of co-benefits, side payments, and the scope for issue linkages.

Together with the core dynamic characteristics of uncertainty, inertia and irreversibilities, cast in the global context, all this implies that appropriate policies must be assessed in terms of their potential to (a) reduce both environmental and economic risks (especially irreversible ones); (b) build options; (c) promote learning and response capacities; and (d) foster cooperation. Obviously, policy should involve a rational balance of costs and benefits, but this does not imply that framing climate change economics primarily in terms of a unitary global long-term cost-benefit appraisal is the most helpful approach. Rather, the challenge may be best characterised as one of ***evolutionary risk management***.

4.2 Policies for innovation

Many assessments (including ours) have noted the central importance of low carbon technology to tackling climate change, and the issue of innovation incentives is raised explicitly in the Stern TOR Pillar 4 Question. Drawing on both the academic literature on technological change, including both the work on endogenous change modeling summarised above and the practical experience of business involvement with the Carbon Trust, Delay and Grubb (2005) proposed five principles for low-carbon innovation policy as follows.

First, learn from history. The combination of governments and energy technology has a decidedly mixed track record. Industrial technologies do not arrive like manna from heaven, but the mindset that energy technology is about big government R&D programmes has been tried before and found wanting. In the 1980s, the US synthetic fuels programme spent many billions of dollars before finally being closed without a single commercial plant, and the UK AGR programme spent far more before finally moving to other nuclear technologies. Most of the technologies that competitively use and supply energy today have matured in the private sector.

Second, innovation, to business, is not a dream for future decades but a continuous process of constantly evolving, improving and selling new products. There are many products and services designed for efficiency that could bear the label "low carbon" right now; one challenge is to accelerate their uptake. This not only reduces emissions directly, but also gives confidence to the private sector that low-carbon innovations will more quickly find markets – and hence rewards. Energy efficiency standards, trading and fiscal schemes that reward the adoption of more efficient, lower-emitting technologies, are an important part of the technology story.

Third, measures that place a price on carbon, like the EU emissions trading system for implementing Kyoto, are an essential part of a low-carbon technology strategy. Robustly implemented, cap-and-trade systems provide a beacon for deeper private sector innovation and investment, and also deter investment in carbon-intensive innovation and capital stock which could prove extremely expensive to reverse as governments respond more strongly to the mounting impacts of climate change over time.

Fourth, although such measures are necessary they are not sufficient. The barriers to deeper innovation are large, particularly when the price signal is so uncertain partly because of the lack of international consensus even on the fact that it is needed. Technology innovation takes a long time as good research becomes a good idea, a proven concept and finally a commercial technology. These earlier stages do not require just R&D, but a whole chain of support to help build businesses out of bright ideas.[3] Financial support, test centres, field trials and pre-commercial markets developed through mechanisms like renewable energy obligations all have a role to play.

Fifth, for the crucial global dimension, recognise that most innovation occurs in a handful of major industrial powers and is diffused globally through investment by multinational companies. The key is to ensure that energy innovation in those major powerhouses – national and corporate – is supported by domestic market incentives, is in a low carbon direction, and is then projected internationally by incentive systems that reward low-carbon investors in developing countries.

[3] On this topic in particular see the joint Cambridge-Imperial submission to the Stern review, published reviews including those by Alic et al (2003) and Grubb (2004), extensive draft material in the IPCC Fourth Assessment WGIII, and various technology-oriented publications by the Carbon Trust (www.thecarbontrust.co.uk).

4.3 Six criteria for international regimes

The analysis in this submission, supported also by the view of innovation policy indicated in the preceding section, suggests at least six criteria that could be applied to test the effectiveness of proposals for international regimes to tackle climate change. An effective regime should:

1. Create incentives to deter or reduce the energy and carbon intensity of ongoing construction of energy-related infrastructure and other capital stock in both developed and developing countries.
2. Create clear and credible signals to the private sector that carbon reductions will have an economic value with a very high likelihood of rising carbon prices for some decades, so that low carbon investments and innovation will be rewarded.
3. Delink the application of such incentives from the question of who pays for them.[4]
4. Urgently improve adaptative capacity and preparatory adaptation particularly in developing countries.
5. Engage mainstream public sector institutions ranging from R&D programmes to infrastructural finance and foreign assistance of both the MDBs and credit agencies.
6. Design institutional structures to be able to adapt the strength of policies, the design of instruments, and the participation in different components of the regime as knowledge increases and national circumstances change.

In addition to the need for greater R&D expenditures, there may be a case for other technology-oriented international agreements. However, supply-side technology strategies on their own cannot deliver effective solutions (eg. for a modeling comparison see Carraro and Buchner, 2004): indeed they appear relevant only to criteria 5 and (to the extent that they increase options) criteria 6. Such approaches have been described by some economists as "second best"; this appears to be an understatement of the limitations of approaches that do not address the top four requirements indicated above.

Emission cap-and-trade systems, if linked to developing country action through mechanisms such as the CDM, can address the first three, though the capacity of the Kyoto system and the EU ETS to address the second criteria is currently seriously impeded by the cycle of sequential allocations. Much thought needs to be given as to how to provide not only investment security, but convincing long-term signals well beyond 2012, whilst striking the right balance with the need for flexibility indicated in criteria 6.

4.4 Concluding observations on national and international strategies

Maintaining and expanding an effective international regime is bound to be extraordinarily difficult. Starting points differ enormously (eg. Figs 1 and 2) and experience has shown that countries different greatly in their willingness to accept responsibilities with respect to climate change. There is certainly scope for contributions that do not require international cooperation, but we have found no convincing evidence that non-cooperative approaches alone can solve the problem.

1. This is partly for basic reasons of equity arising from current global inequalities and related historical responsibilities. It is also because, as indicated, in countries with currently weak infrastructure, development appears to be a pre-requisite for improving capacity to cope with climatic disasters and should thus be accorded top priority in terms of any national resources devoted to climate change issues; and because global abatement is simply more efficient if investment by rich countries can include payment toward emissions abatement in developing countries.

Obviously, cooperative solutions to a problem of global public goods face potential problems of 'free riding.' The experience of international regimes suggests this is not as overwhelming a problem as economic theory sometimes suggests, and we have indicated some tentative reasons above why this may be the case – but the complexity of constructing effective co-operative regimes and the continuing thorn of free-riding undoubtedly undermine the strength of commitments and impede stronger progress. Addressing these problems will require considering three kinds of issues that have hitherto received inadequate policy attention:

- *The role of partial and regional agreements.* Theory suggests that there are more incentives to form several regional agreements than a single global agreement (eg. Carraro, 2005), a finding that appears consistent with the history of trade agreements and perhaps with the recent history of climate negotiations. In addition several agreements may favour the introduction of more policy instruments, enhance the role of issue linkage and regional proximity, increase environmental effectiveness and develop conditions for overlapping coalitions that may then assist in moving towards more global agreement.

- *Incentives to participate (Carraro 1999; Carraro and Siniscalco, 1992).* Extending some of the principles of regional agreements, it may be possible to extend participation incentives towards a global regime. Examples could include technology-related agreements that provide a positive incentive, as well as other forms of side payments or issue linkages.

- *Deterrence of free riding*. If non-participation and free riding by some countries remains a major problem, the international community may ultimately have to consider ways of changing the incentive structures for such countries through 'sticks as well as carrots'. We do not here explore the options, but merely note that many kinds of human institutions have ultimately had to address this question before they become truly effective.

To conclude, our analysis of emission prospects, impacts and mitigation economics has presented evidence that:

[Part 1] Global emissions will rise rapidly without responses that change investment incentives in both industrialised and developing countries;

[Part 2] The resulting impacts of climate change could seriously affect human welfare, particularly but not exclusively in developing countries;

[Part 3] There remain extensive opportunities for emissions mitigation policies that need not incur significant economic costs, will not threaten industrial competitiveness, and will help to accelerate development and diffusion of low carbon technologies.

Climate change is a century-long policy challenge, and tackling it carries opportunities as well as potential costs. It is important not to let what appears to be politically possible at one point in time limit our horizons only to options that are demonstrably inadequate. The logical structure of solutions must be to take the steps we can, to work with those that are similarly willing to take meaningful and effective action, and on this basis to evolve regimes that can in principle solve the problem. In combination with demonstration, incentive and deterrent effects, it is this that will over time make it possible to expand participation in effective solutions.