Yale Symposium

on the

Stern Review

Yale Center for the Study of Globalization
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Introduction
Ernesto Zedillo

Participants at the January 2007 World Economic Forum annual meeting voted climate change to be not only the issue that will have the greatest global impact in coming years but also the one for which the world is least prepared. I voted differently, since I am more worried about other threats to humanity, such as nuclear weapons and the persistence of abject poverty in many parts of the world. But I admit that the Davos vote reveals how the issue of climate change has come to capture the attention that not too long ago it failed to have. This shift in public opinion is increasingly putting more pressure on governments to implement policies for mitigating and adapting to climate change.

Of course, I want to think that this enhanced interest in human-induced climate variability is not purely a temporary fad triggered by a cinematic *tour de force*. We should all be hopeful that the general public, and certainly opinion leaders, are really convinced now that they need to be much better informed about the phenomenon of climate change. This circumstance alone would make political leaders more open and accountable to discussing the issue and, of course, its policy implications.

I am convinced that a large proportion of the serious academic analysis and policy discussions on climate change that we have witnessed over recent months were triggered by the publication on October 30th 2006 of *The Stern Review on the Economics of Climate Change*.

Fortunately, the Review has reignited the debate and rigorous study of the economics of climate change. Moreover, we have even seen experts from other areas of economic analysis bringing their tools into the discussion of this significant problem.

Indeed, we should all be thankful to Sir Nicholas Stern, who, in 2005, was asked by the Chancellor of the Exchequer of the British government to head a group to produce this report. Nicholas Stern very quickly assembled a great team of experts, and undertook to visit a number of universities and institutions to consult about this topic. In a relatively short period of time, Sir Nicholas and his team were able to produce their report, this document, which not only has enormous value by itself -- academic and political value; but it also has value, I insist, because it has motivated other people to come out with new opinions, new analysis and fresh positions on this fundamental question.

In the spring of 2006, I had the pleasure of meeting with Sir Nicholas and members of his team on a visit they made to Yale University. At that time, he expressed his willingness to present the Review here at Yale, under the auspices of the Center for the Study of Globalization. His interest was in participating in an academic analysis of its findings with scholars of the highest reputation in this field.

This event is the realization of that conversation. We welcome Sir Nicholas and his team with gratitude and recognition for their immensely valuable work.

Our event is divided into two parts. This morning we will have the opportunity to listen to Sir Nicholas and his team making a presentation of the report. For this session, we are also privileged to have Chris Hope from Cambridge University who is the leading author of the PAGE model. This model was used extensively in the preparation of the Review. We sincerely thank Chris for making the journey from Cambridge and for his important contributions in this field. We are also honored to have Dean Gustave Speth of our School of Forestry and Environmental Studies who will have the last word in this morning's session.

For the afternoon, we have assembled an impressive group of scholars who will make a review of the *Review* in the presence of Sir Nicholas himself. The afternoon session will be completed with a discussion between Sir Nicholas and his reviewers.

We thank William Nordhaus, William Cline, Gary Yohe, Robert Mendelsohn, Scott Barrett and Jeffrey Sachs. Needless to say, these authors' contributions are an essential part of this symposium.

I will now call Sir Nicholas Stern to present to us his impressive Review.

Chapter 1: Findings of the Stern Review on the Economics of Climate Change

Sir Nicholas Stern

In June 2005 the Chancellor of the Exchequer, Gordon Brown, asked me to conduct a review of the economics of climate change. This was not to be like the reviews that I and many of you have done of academic literature, in which you try to put a whole literature in perspective, give it a structure, and try to be exhaustive and fair to everybody who's contributed to that literature.

Our task was to produce a different kind of review—one that would help people involved in policymaking come to a view on what would be a sensible way forward, given what we now know. So, it's a review that speaks to policy, and is mostly about policy.

To make suggestions about policy, you have to come to a view on what kinds of things should be done. In the case of climate change, how strong should the action be? How urgent is it? Those questions are the first steps, and then you look to what kind of policy tools can steer you in a sensible direction. Thus the review has two halves: the first is about what kinds of actions are necessary in the face of climate change, on what scale, and when, and the second half looks at the details of policy design. I'm guessing that the participants here today are going to take the modeling side of the Review quite seriously, so I want to talk about that, too. But as all modelers should know, formal modeling is only one part of the argument and one part of the contribution of economics. Thus I hope that in the discussion we can get into the policy issues more deeply.

Why Bother About Climate Change?

First it is worth thinking about why one should bother about climate change at all. I have to say that I came to this question in July 2005 with a very open mind. I knew what the greenhouse gas effect was, but I hadn't thought through, or been closely involved in discussions of, what might be sensible policies to approach it.

Three reasons are advanced for why one can relax and forget about climate change. I think they are fundamentally misguided, but it's important to recognize them. One is that the science is all wrong, that global warming is "the biggest hoax ever perpetrated on mankind," similar to how one US senator has described it. That is for the scientists, but the weight of evidence is now such that most people would see this point of view as simply absurd. The February 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) sets out the evidence in a very convincing and clear way.

The second reason for denying the problem of climate change is to say that human beings are fantastically adaptable; they can cope with anything that comes their way. Human beings are, of course, adaptable, but if we go on with business as usual, the risks we now run, for some time next century, are for global warming by five, six degrees Centigrade and above, relative to pre-industrial times. Such a rise in temperature would be earth-transforming. Five degrees Centigrade is the difference between now and the last ice age 10 or 12 million years ago. The kinds of places we could live and how we could live our lives would be radically transformed in ways that are very hard to understand. For one thing, these kinds of transformations involve very big movements of population, and we know from the experience of the last century or so that the world hasn't got any better at handling big movements of population. So, I think the idea that we can adapt to anything that comes our way is reckless, relative to the kinds of things that could happen.

And the third reason for denial is that "Whatever the effects are, they're way off in the future, and I'm not particularly bothered about the future, so I'm not going to do anything." That attitude involves what some economists would call pure time discounting, and I'm convinced that such time discounting at a heavy rate would be viewed by most people as unethical. It involves discrimination between individuals by date of birth. The ethics of climate change is a discussion that we ought to have. Whilst markets do have some information, it is not easy to use without very strong and fairly implausible assumptions. And there's no way we can simply read off the relevant ethics from the behavior of markets: we cannot see a collective expression in the markets of what, acting together, we should do for 100, 150 years' time. This is an area in which reasonable people can differ, but in which reasonable people are obligated to have a serious discussion.

The economics of climate change is fundamentally about the economics of risk. And if you act on climate change and invest in bringing forward new technologies, and it turns out to be the biggest hoax ever perpetrated on mankind, you will still have acquired a lot of new technologies that are probably quite useful. If, on the other hand, you assume it is the biggest hoax ever perpetrated on mankind and you do nothing, then you may fairly quickly end up with a lot of irreversible and severe damage from which it will be very hard to extricate yourself.

The Economics of Climate Change

Let me now move directly into the economics. If you emit greenhouse gases, you cause damage to other people, you influence their ability to produce and consume, and that's what economists mean by an externality. London dealt with the familiar externality of traffic congestion by the price mechanism: it introduced a congestion charge for vehicles entering the middle of the city, though not until the average vehicle speed had slowed to walking pace. Delhi moved to green (actually CNG) auto rickshaws and buses by government fiat, after people had been dying very heavily of bronchial and other diseases and the exhaust-gas problem had been elevated into a question of human rights: the Supreme Court in India intervened.

But climate change is an externality in a very different form from what we are used to. It is global in its origins, and global in its effects. Greenhouse gases emitted in Australia and New Haven and London all have the same effect on the atmosphere. The impacts occur throughout the world, though of course, they differ in different parts of the world. Climate change also occurs over the very long term, and this means that we can be in a crisis without actually seeing the direct effects immediately—there is no equivalent of directly experiencing the cars slowing to walking pace in London. So, politically, it can be difficult to get action. Climate change is also very uncertain. We don't know exactly how much emissions will arise from different types and levels of economic activity or how much a given concentration of greenhouse gases raises temperature. We don't know exactly what effects different rises in temperature have on weather patterns. And we don't know exactly what effect weather patterns of different kinds are going to have on production and consumption. There's lots of uncertainty right through this chain, and it has to be taken into account directly. And, of course, the effects of climate change are potentially very large and irreversible.

Now, what are these effects? Mostly they happen through water: through storms, droughts, sea-level rises, and floods; for example floods of the kind we saw in Mozambique in 2000, which took many thousands of lives and knocked 15 % off that country's GDP. Some effects happen directly through heat, like the heat stress we saw in Europe in 2003, in a summer that will probably be normal by 2050.

Such events occur in a stochastic way but can be very big and very disruptive. What we're seeing now, of course, is only on the basis of 0.7 degrees Centigrade of warming, relative to pre-industrial times, rather than the kinds of effects that the world is going to experience as the temperature rises further. Even if we start acting strongly and urgently now, we shall probably get three or four times this amount of temperature rise. Of course, if the rise goes up to five or six degrees Centigrade, we shall see something that is quite hard to imagine. Figure 1 illustrates, with the arrows reflecting growing risk and impact, how much worse the effects will become if we go up into these higher temperatures.

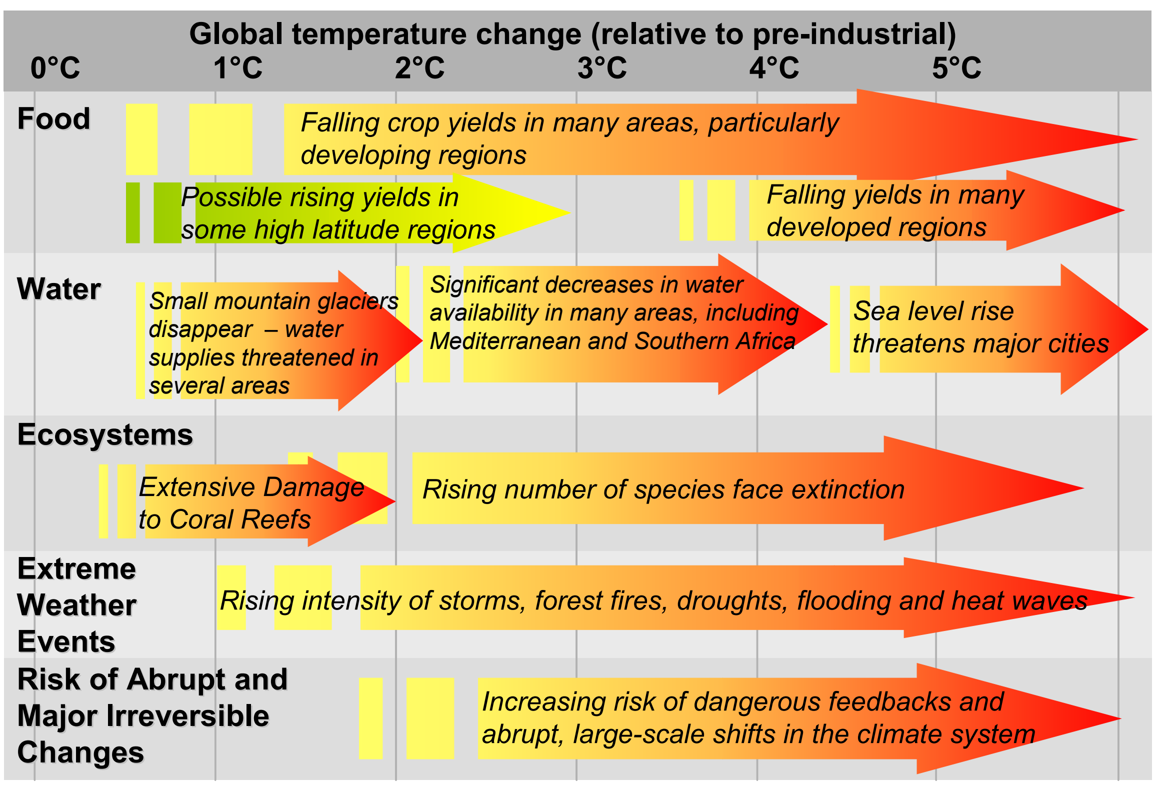
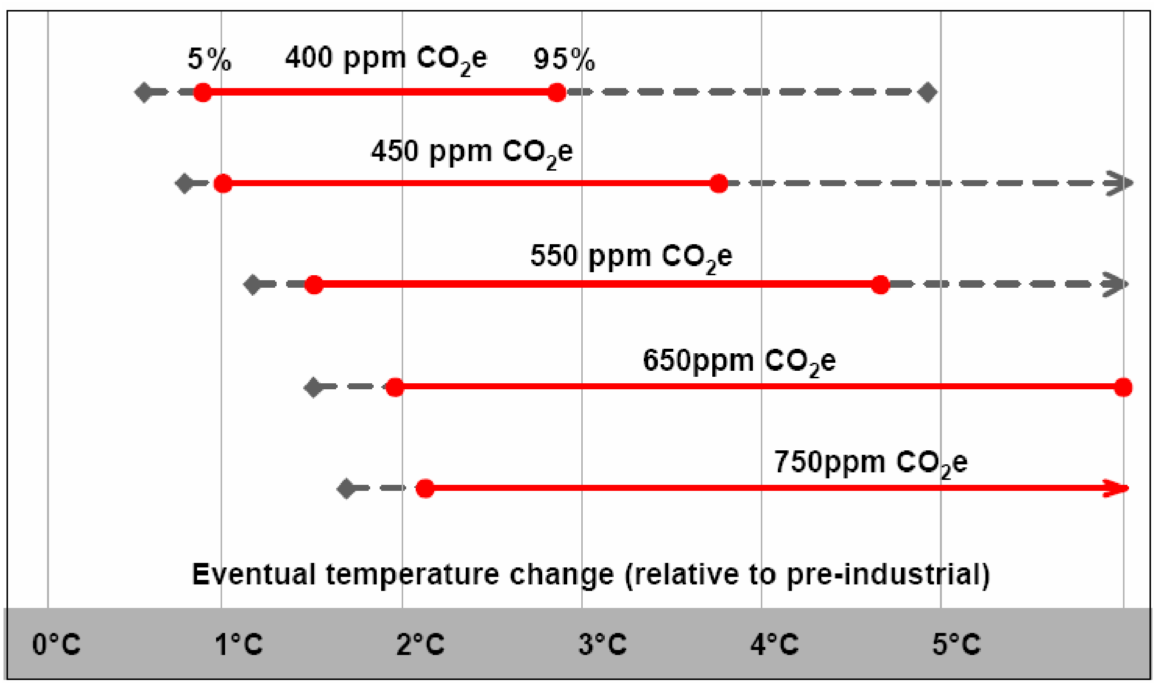


Figure 1: Projected impacts of climate change

It's important to emphasize the need to consider these higher temperatures. Much of the earlier literature—perhaps understandably, given the state of scientific evidence then—focused on temperature increases of only two and three degrees. Those are, of course, serious issues for study, but it is now quite broadly recognized that the analysis must go way beyond that, because temperature rises of four, five degrees and more can happen if the world continues with business as usual.

What about the relationship between the greenhouse gases in the atmosphere and temperature? A key scientific advance of the last four or five years, from the point of view of this type of analysis, is that scientists are now offering us a clearer understanding of the probabilistic relationship between the rise in concentration of greenhouse gases in the atmosphere and the rise in global temperature. Figure 2 illustrates the kind of probability distributions that scientists are now indicating.

Figure 2: Stabilization and eventual change in temperature



The figure shows eventual temperatures relative to those of pre-industrial times. I emphasize the long lags in the system. The red intervals here are 90 % confidence intervals, so that if you take that particular scientific probability distribution, you have a 5% chance of being off the top end and a 5 % chance of being off the bottom end of that distribution. We drew dotted grey lines there because we have chosen among the possible scientific distributions, and have been moderately conservative in our choice, sticking fairly closely to the kinds of probability distributions used in the fourth report of the IPCC. The dashed lines represent the results from the full range of studies. We drew on the same science that IPCC was drawing on, not as scientists but as consumers of science. And I emphasize this because some authors have suggested we've exaggerated the science in some way. In fact we've just taken science from the same sources as the IPCC and have been fairly conservative as a comparison of the Stern Review and the Fourth Report demonstrate.

Figure 2 thus shows the kinds of risks that the world will be running. We are currently at 430 parts per million (ppm) of carbon dioxide equivalent (CO2e). We're adding about two-and-a-half ppm a year. It's very hard to get carbon dioxide back out of the atmosphere. So, even if that flow of two-and-a-half parts per million a year doesn't speed up, in eight years, we shall be at 450 ppm. But if we do not do much about climate change, that two-and-a-half ppm will go on rising. Though it depends how you model these things, the average rate could easily be four parts per million a year over this century. That would take the greenhouse gas level higher than 800 ppm CO2e, dropping off the scale in Figure 2.

At a greenhouse gas level of 850 ppm CO2e, we have more than a 50 % chance of global warming of more than five degrees Centigrade. So, to talk about the risks associated with temperature increases of five degrees, six degrees, seven degrees Centigrade is not at all fanciful. These are the kinds of risks the world runs if, as a world, we do nothing about curbing emissions.

So, here we need to make a judgment about what policymakers should do. This judgment can be made by comparing the risks we face from different levels of concentration, and paths to stabilization of concentrations, and the costs associated with the paths that stabilize at these levels. Thus we ask, for example, is it worth paying the costs of stabilizing emissions at 550 ppm CO2e to avoid the additional risks of temperature rises beyond this?

What we offer is the suggestion that 550 parts per million of CO_2e is an upper limit on the kinds of risks that it would be sensible to run. Let us be clear, this is a dangerous place to be: 550 ppm gives a 50/50 chance of global warming above or below three degrees Centigrade, and quite a significant probability of its being above four degrees Centigrade. In some models, it gives a small probability of being above five degrees Centigrade. Given how close we are to 450ppm, this represents the most ambitious target that is likely to be feasible. Those who believe that an upper limit of 550ppm C02e is too radical a curb on emissions must come clean and declare that they are ready to accept the very heavy risks involved.

So, this is a view of the stocks and the risks associated with them. After discussing our analytical framework I'll move on to describe the flow paths that would be consistent with stabilization.

Analytical Framework of the Stern Review

Throughout our work on the Review we tried to bring in very strongly the economics of risk, acknowledge uncertainties, flush the ethics out into the open, and see climate change as very much an international action problem.

Modeling is a valuable supplement to the kind of risk analysis that I was just pointing to. But climate change is a very complex and big problem, and when you think of it on the appropriate scale and detail you realize the very simplistic nature of the structure and parameters you can feed in to an overall model. Inevitably the modeling route leaves out a great deal of what's interesting, and in big aggregated world models, whether of climate change or other concerns, you lose the ability to analyze the kind of risks that are run at the regional and at the country level. Of course, when you take the very broad-brush modeling approach, rather than adding up in any direct way these local risks, a tremendous amount starts to turn on the design of your model. So, you always have to be aware of the model structure you are using and the extent to which the kinds of results that come out are influenced by the kinds of things that you put in. In that respect, climate change is a modeling area that's no different from any other. But in this case the magnitude and dimensions of the effects and very long time periods make this problem much more severe than we usually encounter in economics.

Our model choice was strongly influenced by the importance of risk and uncertainty. We chose Chris Hope's PAGE model because for us it was the easiest available model with which to incorporate uncertainty in an explicit way. Second, Chris

Hope was generous in helping us use it. Third, it is valuable in that it is designed to reflect the results that come from other people's models thus ensuring that it is not, in any sense, an outlier.

To assess damages, you have to have a criterion, and the criterion we used—expected utility—is quite standard in the literature on the economics of risk. Damage from climate change is something that takes place over time, so it can be treated as the expectation of a social utility integral. In economics that is a fairly standard way to approach this kind of problem.

To compare damages with costs, you have to calibrate the criterion function in some way. To talk about the sum of social utility or the expectation of the sum of social utility over time in terms of expected utils is not something that most people find it easy to get their heads around. So we used a concept that James Mirrlees and I suggested some 35 years ago: the balanced-growth equivalent (Mirrlees and Stern 1972). In Mirrlees-Stern you calibrate a social utility integral in terms of the initial consumption level that would produce that utility integral if this consumption grew at some standard rate associated with growth in the model. Thus you calibrate the expected social utility integral using the balanced-growth equivalent (BGE) by looking at the initial consumption level, which you think of as growing steadily, and measure gains and losses in terms of that initial consumption level. But, of course, we should think of the gain and loss applying to the whole balanced-growth equivalent path.

This is also a useful tool for incorporating risk analysis as it acts also as a certainty equivalent. We simply calibrate the expected utility integral in terms of the certain initial consumption level growing at the standard rate which produces the expected utility integral. Differences in balanced growth equivalents with and without climate change in this context can be interpreted as the simple annual insurance premiums we'd be prepared to pay to avoid the uncertain losses arising from climate change. They represent the annual premium that we'd be prepared to pay each year to avoid the equivalent paths as a result of climate change.

You can think of the overall expected social utility criterion for damages together with the BGE calibration as embodying three sorts of averaging: averaging over time, through the utility integral including whatever discount factor you attach to it; averaging over space and individuals, because these are effects occurring in many parts of the world and to different people in different ways; and averaging over outcomes. So, when we express the damages that occur from business as usual, relative to a world where climate change does not take place, our estimates involve those three kinds of averages put together. It's important in thinking about them to keep in mind these averaging processes.

How you do the averaging will have a strong effect on the results, and that's one feature of the modeling that you need to think about in interpreting our results in the Review. When we do the averaging, we're discounting, we're treating risk aversion, and we're treating equity. Both the model structure and our judgments about ethics will drive the results. Later I'll discuss the sensitivity of the results in relation to those two things.

Figure 3 shows the equivalent loss in consumption each year from the effects of business as usual climate change. The 90% confidence interval is shown underneath. In this Figure there is a little bit of sensitivity analysis: you bring more things into your account of damages as you move down from the first row to the second column, from very narrow GDP-like estimates (in economic sectors such as agriculture and tourism) to estimates that involve much broader views of impacts (non-market impacts such as on health, deaths and ecosystems). So incorporating a broader set of impacts increases the central estimate of damages from 5% of consumption each year to 11%.

Figure 3: Aggregate estimates of impact

	Market impacts	Broad impacts
Baseline climate	5% Range 0-12%	11% Range 2-27%
High climate	7% Range 1-17%	14% Range 3-32%

Note: The figure shows the magnitude of effects in the middle of the plausible range, taking into account sensitivity analysis in the Review.

The other aspect of the sensitivity here is as you move across the rows, looking at different kinds of probability distributions for the impacts of climate change, moving from 'baseline climate' to 'high climate' introducing in a small way some aspects of the greater uncertainty that science is aware of but has not yet been able to model in a very explicit way. The kinds of probability distributions that the IPCC has calibrated and worked with include only certain things that could happen. These distributions don't say very much, for example, about carbon feedback mechanisms, because IPCC has not yet got a clear understanding of the levels of risk associated with these mechanisms. Scientists don't know enough about them yet, though they know those kinds of effects are there. So in the model we have deliberately left out large areas of uncertainty that have yet to be researched. We did include just one of these possible effects: the melting of the permafrost and the methane release that would result from that. That's reflected in the difference between the first and the second row in Figure 3. It is equivalent to an additional 0.4 degrees of temperature change. The latest IPCC report suggests that these feedbacks could add up to a further degree temperature change by the end of the century. Not surprisingly, you get higher estimates of damages if you include more things in your damage list and if you include broader probability distributions. This is a very important sense in which we have underestimated the damages.

The set of issues around intra-generational income distribution is not represented here, in the formal aggregate modeling because of the time constraints we faced in producing the Review. They are very important to our overall approach however, and are very prominent in our detailed disaggregated analysis. We did speculate informally about the effects of bringing intra-generational distribution into the modeling story. You can do this by relating weighted growth rates to the utility functions that underlie them, and we would suggest that you probably should scale these up by a factor of a quarter or a third. François Bourguignon has done some back-of-the-envelope calculations on that kind of thing, as well, and he gets similar kinds of numbers. So, that's how we got to the 5% to 20% loss in consumption that is often quoted.

Averaging over time is important. Those of you who are not economists, please excuse me while I discuss briefly some of the formal aspects of ethical judgments. We talk about the elasticity of the social marginal utility of income, which we represent by η, and we talk about the pure time discount rate (δ), which you should view as the degree of discrimination between people by date of birth. So, in other words, pure time discounting says that an individual who is born 30 years after another individual would, if you use a pure time discount rate of two per cent per annum, be given half the weight of the individual born earlier. Many people for a century or more have thought hard about the pros and cons of discounting the utility of future generations, and I still have not heard a convincing ethical argument for indulging in that kind of discrimination, particularly in the context of issues which affect the entire planet. We may know lots of people who don't care about the future, but that doesn't mean this is the right ethical standard to apply for such an important issue, profoundly affecting the welfare of future generations.

For the social marginal utility of income, we used as a base case η equals one, which is quite a standard value in the literature. This value means that if somebody is five times better off than somebody else, then an increment in consumption to the person who is better off has a 20% (one over five) weight relative to the person who is worse off. Thus we value an increment in consumption to the poorest at five times an increment in consumption to the richest. Using η equals two would be to say that the person who is five times better off than the other person has, for marginal changes, a one-twenty-fifth (or one over five squared) weight. So, if η equals two, you would be arguing that you could take a dollar from somebody who is earning $150,000 a year and give it to somebody earning only $30,000 a year then even if 95 cents of that dollar disappeared on the way, it still would be a good idea.

A problem in this context is that η is doing more than one job; η is not simply representing egalitarian values but is also a measure of relative risk aversion. This double role might be used to help a judgment as to what plausible social judgments on η might be. However we know from the risk/uncertainty literature that the expected utility model as a description of behavior is problematic. And, in any case, a link from behavior to social values would be a further and difficult step. That doesn't mean that the evidence is irrelevant, but it's difficult to interpret. In a paper we put up on the Web at the beginning of February, we tried to explore some of the philosophical issues and what might be relevant evidence. In this discussion that we must have about ethics, evidence on attitudes to redistribution, attitudes to risk, and attitudes to saving is all relevant and important.

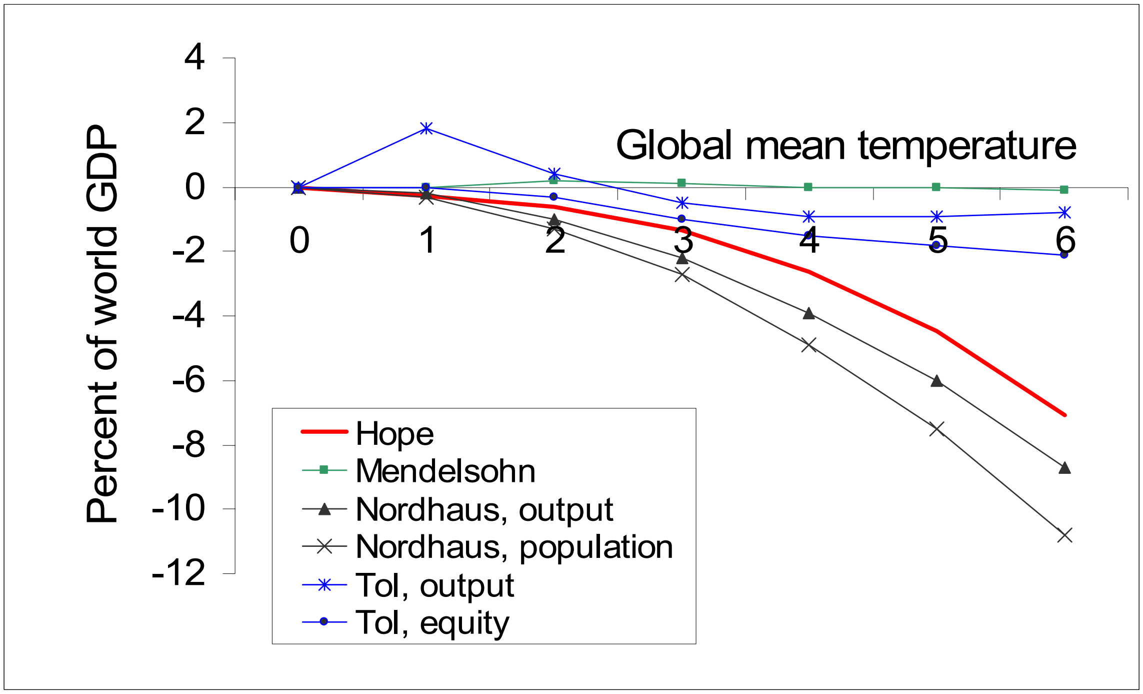
One of the issues that arises with $\eta = 1$ and low δ is that these choices place a big weight on the future. So, it is important to ask "What if you put slightly less weight or a lot less weight on the future? How does it affect the results?" It is important to place this both in the context of sensitivity analysis of the model as a whole and in an understanding of the role of this type of modeling in the overall argument.

Assumptions, Uncertainties, and Results

Why do we get results that are bigger, in many cases, than previous examples in the literature? Is it because we exaggerate the relationship between temperature and damages? I don't think so. The red line in Figure 4 represents the assumptions about impact on global GDP from changes in global mean temperature that were used in Chris Hope's PAGE modeling, and it is roughly in the middle of the range for the literature. Some authors have been more optimistic about the damages likely to be caused by rising temperatures than we were, others less so.

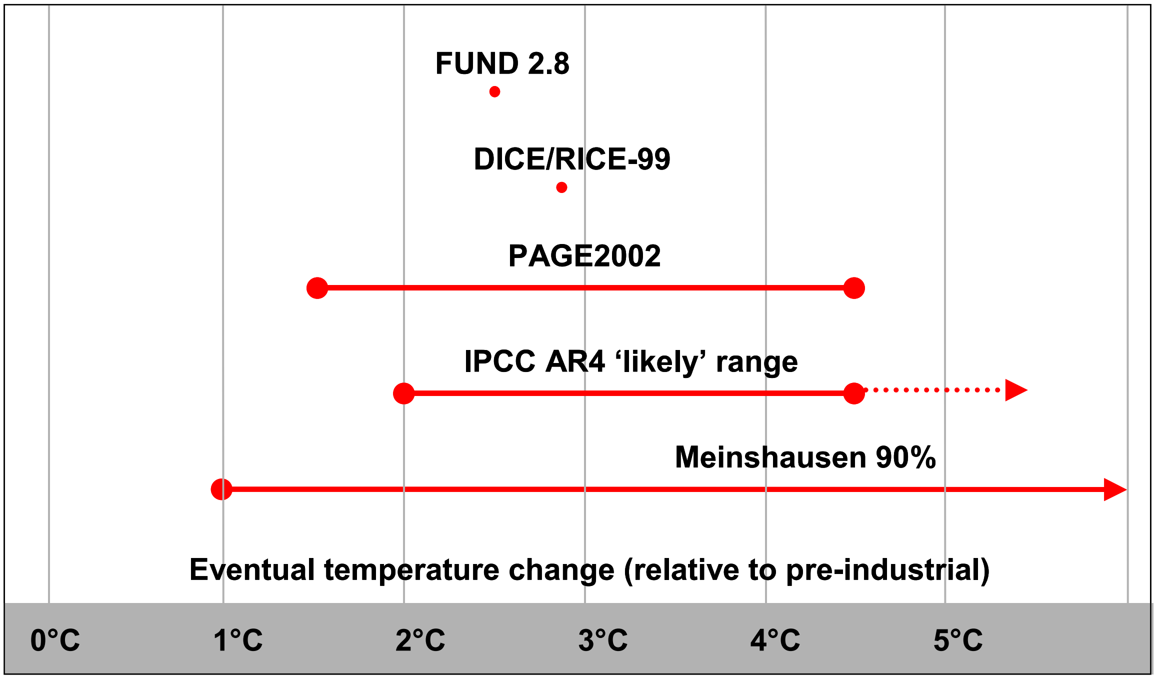
My own view is that the set of assumptions we used understates the damages that rising temperatures will cause to world GDP. It doesn't take into account that at five or six degrees of warming, we're into territory that we really don't understand (our probability distributions account only for 'known' uncertainty not Knightian) and could be very worrying for example in terms of the effects of very large movements of population, including conflict (where it is hard to assess likely aggregate costs). In a moment I'll come to what difference it makes to damage estimates when you assume that damages are more sensitive to temperature.

Figure 4: The PAGE model and other Integrated Assessment models



What do we assume about climate sensitivity, the relation between stocks of GHGs in the atmosphere and temperature/climate? The concept of climate sensitivity, which seems to be standard in the literature, measures how much the temperature eventually goes up if you double the amount of greenhouse gases in the atmosphere. Using the PAGE model we look at what happens to temperature if we double the amount of CO_2e in the atmosphere and move from the 280 ppm of pre-industrial times to about 560 ppm. From Figure 5 you can see that the distributions we used are quite cautious but not far off those in the standard literature. The dotted line shown for IPCC refers to the carbon feedback mechanisms I mentioned earlier for which there is some suggestive evidence, but not yet enough to be built fully into the probability distributions.

Figure 5: Estimates of climate sensitivity from Integrated Assessment models compared to Global Climate Models shown in the results of the IPCC and Meinhausen range from eleven studies.



Our assumptions on the relationship between stocks of greenhouse gases and temperature, too, have been within the normal range in the literature. However, we have been very deliberately stochastic here, where some previous studies have not, in my view a crucial omission from these models given the importance of risk to the whole set of issues. These probabilities have become available from the IPCC only in the last few years, but it is crucial now to make use of them in a way that allows us to speak explicitly about the role of risk.

Sensitivity Analysis – What Drives the Results?

Turning now to the sensitivity analysis. Model outputs are driven by model structures and assumptions. We have carried out formal sensitivity analysis, using PAGE2002, the details of which can be found on our website. Figure 6 summarizes the sensitivity of the Review estimates to the four key issues: ethics and discounting; the treatment of risk and uncertainty; adaptation; modeling high-damage scenarios. In each case, the base case in Figure 6, from which deviations are reported, is our 'central' modeling case[1]. The total cost of climate change is derived from a comparison of the 'balanced growth equivalent' or BGE of consumption without climate change to the BGE of consumption after climate damage and adaptation costs have been deducted (see Box 6.3 of the Review)[2].

Figure 6 Sensitivity of total cost of BAU climate change, in terms of a loss in present global mean per-capita consumption (on a BGE path), to various issues.

Variation	Central case	Sensitivity	Change in mean total cost of BAU climate change (percentage points)
Ethical aspects			
Increase in pure rate of time preference, δ	0.1% per year	1.5% per year	-7.8
Increase in elasticity of marginal utility of consumption, η	1	2	-7.5
Model structure			
Failure to incorporate risk and uncertainty	Expected-utility analysis	'Best guess' model based on mode values	-7.6
Increase in relative adaptive capacity of Africa, India and Southeast Asia, and Latin America	Higher and constant relative vulnerability in these regions	Vulnerability instantly falls to that of EU in 2100	-1.5
Increase in damage function exponent, γ	Triangular probability distribution (min=1; mode=1.3; max=3)	3	+23.3
Incorporating recent science	Baseline-climate scenario	High-climate scenario	+3.6
Incorporating risk of 'catastrophic' climatic changes	With risk of catastrophe	Without risk of catastrophe	-2.9

Much attention has focused on our assumptions on value judgments, so it is important to examine the sensitivity of the model results to these. I would recognize that a higher η is tenable especially if you account for responsibility as suggested by Dasgupta. If you increase the elasticity of the marginal utility of consumption, η, as shown in Figure 6, you get two effects. First, because of greater egalitarianism from higher η, if the current generation is less well off than future generations you will put a stronger weight on the welfare of the current generation and less on the damage in the future from climate

[1] This comprises the baseline-climate scenario, with market impacts, non-market impacts, and the risk of abrupt, large-scale and discontinuous or 'catastrophic' climatic changes. The pure rate of time preference, δ, is 0.1% p.a., the elasticity of social marginal utility of consumption, η, is 1, the damage function exponent, γ, is sampled from the range 1-3 (mode=1.3), and expected-utility analysis is carried out.

[2] It summarises simulated losses over time, regions of the world and possible states of the world in terms of a permanent loss of global mean per-capita consumption today. In the central modelling case, this loss is around 11% (see Table 6.1 in the Review).

change. This can make quite a big difference as you move into the future. Second, if you increase the value of η, you also increase aversion to risk, which would affect damage estimates in the opposite way as more damaging outcomes are discounted less heavily and attain a higher expected utility weight. But with the kinds of structural assumptions that we're using, the inequality effect and therefore the stronger discounting effect, dominates the uncertainty effect. With bigger risks, however, the balance can tilt the other way. And these bigger risks may actually become viewed as more appropriate as the science gathers more evidence and analysis.

You can also increase the pure rate of time preference. But, as we emphasized in the Review, if you do that, there will always be a rate of time preference high enough to render future climate effects to have negligible value. If you use pure time discounting of 2% or 3% for a hundred years, you are putting a tiny weight on what happens after a hundred years. If you have a high enough pure time discount rate, neither the economics nor the science matters. As I said, one cannot avoid this ethical discussion, because how one values the welfare of future generations has a direct and very powerful influence on the results. And we were very explicit about that in the Review.

As I noted earlier, we did not formally incorporate a concern for intra-generational income distribution, though we did try to do so in our disaggregated regional work, and with considerable detail. In the modeling work we explored fairly informally and suggested that this pushes up the estimates of damages substantially. Further, a higher η would place still stronger emphasis on the intra-generational distributional issues.

Ethics are important but model estimates, of damages or otherwise, are driven by a lot more than assumptions about ethics. For example, the choice of a lower emissions scenario in the baseline would lower the assessment of the damages, and diminish the case for urgent action. On the other hand, a higher exponent on the damage function, a more comprehensive treatment of uncertainty or allowance for a wider world income distribution (for most of the modeling there is simply aggregate consumption and consumption per head) – all of which are plausible - would raise the projected impacts potentially quite significantly. In fact, it is notable that the degree of convexity of the damage function is perhaps more important than anything else is driving the aggregated results.

My own view based on discussions with leading scientists, particularly thinking about warming of five, six degrees, or seven degrees Centigrade, is that we may have underestimated the degree of convexity, the strength of the relationship between temperature and damages, or at least we ought to allow for it being stronger. In other words for the higher temperatures damages may rise far more quickly with rises in temperature than in the base case used in the model here. You can investigate this stochastically: you can say "we're not sure what sort of convexity to put in", and you can make that parameter one of the Monte Carlo parameters that Chris Hope uses, (and it is indeed a Monte Carlo parameter). We found, not surprisingly, that when we assume a stronger relationship between temperature and damages, the model results show much larger damages.

In addition to the issues we have discussed in detail, there are many other assumptions and judgments that will affect results. We summarize a selection of these in Figure 7, along with a back-of-the-envelope calculation of how they will affect our estimates. For example, if economic growth is faster than we assumed, you get sharper discounting, because future generations will be richer, but you also get emissions going up more quickly. So, those two things act in different ways, but our belief is that, net, faster growth would probably increase the damages estimated here (line 3, Figure 7).

Figure 7. Further sensitivity of total cost of BAU climate change to various assumptions.

Variation	Central case	Sensitivity	Change in mean total cost of BAU climate change (percentage points)
Ethical aspects			
Accounting for intragenerational income distribution/equity weighting	Not included	Included	+6
Population growth	IPCC SRES A2 scenario, extrapolated by Hope (2006), gives global population of 21.5bn in 2200	Reduce population growth by 40% over modeling horizon, whilst holding emissions constant.	-4
Model structure			
Output growth	200-year average of 1.3% per capita	Increase annual per-capita growth by 1%	+
Terminal conditions	Modeling horizon ends in 2200, emissions fall instantly to a rate equal to the Earth's natural capacity to absorb GHGs, allowing the impacts of climate change to stabilize	Continued emissions growth post-2200	High sensitivity ++
Aversion to irreversibilities and ambiguity	None	Included	+
Rise in the relative price of environmental goods compared with other consumption goods	Utility is only an aggregate function of total consumption	Utility is a function of both consumption and environmental goods and services	+2
Inclusion of 'socially contingent' risks, e.g. conflict and migration	Not included	Included	++

Commentators have rightly pointed out that our results are sensitive to terminal conditions. We've assumed that damages fall away after 2200, or at least stay constant (in percentage terms) in a world where business as usual emissions continue to rise unabated. Of course, if we allowed damages to continue growing beyond that date, our estimates would increase (line 4, Figure 7). In such circumstances, further areas of risk and uncertainty are left out in addition to the omitted carbon feedbacks already noted. Nor have we accounted for aversion to irreversibilities and ambiguity (unknown possibilities), that is, risks that we are unable quantify, for example those associated with pushing temperature into uncharted territory.

We emphasized that there may be more damaging feedbacks and impacts at high temperatures that we have not yet identified. We explained in Chapter 2 of our review (and referred to the work of Claude Henry) that the Knightian distinction between risk (known probabilities) and uncertainty (unknown probabilities) is likely to be important here. Whilst exploring this issue and pointing to relevant analytic techniques, we have not tried to estimate the consumption we might be willing to forgo to avoid this ambiguity.

So, I think there is actually more weight in the tail of the damage distribution than is represented in our results. Except for that concerning population size, most of our other sensitivity analyses would point to higher estimates than ours. So, on the whole, on the structural side of these models, we've been probably very conservative. That is to say, from the sensitivity analyses a wide range of possible estimates emerges, but in most cases the relevant variations in structural assumptions would increase our damage estimates.

Figure 8. Explanation of further sensitivities

Accounting for intragenerational income distribution/equity weighting	In the Review, we did not have the opportunity to model the regional impacts of climate change. Given a positive elasticity of marginal utility of consumption, consistent valuation of the impacts of climate change across time, risks and regions of the world implies that consumption effects in poorer regions of the world should receive higher weight, just as increments in global consumption today should be weighted higher than increments in global consumption in the future, if the future is richer.
Population growth	Where population growth is exogenous, the social welfare function is weighted by the total size of the population. In Chapter 6 of the Review, we used an extrapolated version of the A2 scenario from the IPCC's SRES (Nakicenovic and Swart, 2000; extrapolated by Hope, 2006) to project GHG emissions, output and population growth.[3] Although the A2 scenario appears, on current trends, to predict a sensible path for GHG emissions, it forecasts a very high global population, reaching around 21.5 billion people in 2200 (as extrapolated by Hope, 2006). As a result, the cost of climate change will be higher than it otherwise would have been, all else equal, because high per-capita costs of climate change next century are multiplied by a high global population.
Output growth	A change in output growth will produce an ambiguous result. Higher annual growth will result in higher emissions. Given the close relationship between output and emissions, a 1% increase in annual growth would likely raise the atmospheric stock of GHGs by a factor of 3 or 4 by early next century, in turn probably quadrupling climate impacts by then. On the other hand, the average annual consumption discount rate would increase by 1 percentage point, before climate impacts. The effect is likely to be finely balanced at first, but reasonable assumptions suggest that steeply rising climate damages, brought about by such a high stock of atmospheric GHGs, dominate over the longer term[4].
Terminal conditions	In other words the length of the modeling horizon and what is assumed to occur thereafter. The PAGE2002 modeling horizon runs until 2200. Thereafter, the Review in effect assumes that emissions fall instantly to a rate equal to the Earth's natural capacity to absorb GHGs, allowing the impacts of climate change to stabilize and the stock of GHGs to rise very slowly. The longer the modeling horizon, the higher the costs of climate change, though in the very longest run, the coupled climate-economy system may eventually regulate itself, even in the absence of policy.
Aversion to irreversibilities and ambiguity	We did not explicitly account for aversion to having to make irreversible decisions – the number of such decisions is likely to increase in line with the stock of GHGs, adding further to costs. In addition, we did not formally take account of ambiguity aversion, which becomes important where the consequences of climate change cannot adequately be represented by a continuous probability distribution.

[3] Our regional growth rates were converted from market exchange rates to purchasing power parities.

[4] Output growth would also affect adaptive capacity and willingness to pay to avoid non-market climate impacts. Again the effect is ambiguous. We deal with adaptation separately, but note that willingness to pay to avoid non-market impacts is a quantitatively important component of most IAMs that include them (see Warren *et al*., 2006).

Rise in the relative price of environmental goods compared with other consumption goods	We can expect the relative price of environmental goods to rise compared with other consumption goods, but this is not captured in a utility function where aggregate consumption is the only numéraire. Thus climate impacts are likely to be underestimated (e.g. Tol, 1994).
Inclusion of 'socially contingent' risks, e.g. conflict and migration	No IAMs yet take explicit account of socially contingent costs, which would increase damage estimates.

The damage-impact estimates in the Stern Review are higher than some of the existing literature for three reasons. First we used the latest science in 2005/06 and this suggests larger temperature changes than the previous studies (which reflected the latest science at their time, many have data/estimates from the late nineties). Secondly we have explicitly included in the analytics of the economics of risk the latest probabilistic assessments: climate science now is much more specific on probabilities. Finally, as discussed at length today we have dealt with the ethics explicitly and have argued that the values likely to emerge from this more explicit discussion would increase the weight given to the future and thus estimates of damage compared with some of the more casual ethical treatment of the earlier literature. While most attention has focused on the last of these revisions, all three are very important to our results. Indeed one can argue that for plausible parameter values each had a similar impact on the estimates.

We should also explain key elements from Chapter 13, the summary chapter for the first half of the report which puts together the preceding chapters including the modeling chapter (Chapter 6). Many commentators seemed to have overlooked this in their decision to focus on Chapter 6. It is very important to see the sequencing of the logic here.

In Chapter 13, inter alia, we explain that the key question of the first half of the Review is whether we would pay 1% of GDP to avoid the risks of damages discussed in Chapters 1, 3, 4 and 5 (with multidimensional regional flows). Thus chapter 6 is a useful but supplementary analysis. And we stress that stabilization between 450 and 550ppm CO_2e would avoid most of the damages from climate change (around 90%) but not all.

Overall, from this discussion of sensitivity, there seems little justification in changing our broad view that the cost of avoidable climate change, (i.e. comparing a 'curbed' emissions path with BAU) is well in excess of the cost of stabilizing GHG emissions in the range of 450-550 ppm CO_2e. We did not undertake an explicit optimization, data constraints and uncertainties make this too ambitious. Those that have taken this route rely on ad-hoc assumptions, to which results are likely to be very sensitive. But in Chapter 13 we do proxy an optimization process to determine the likely stabilization range. Hence we summarized the literature which shows that the incremental raising of emissions above 550 ppm CO_2e adds more to damages than it costs to reduce emissions by a ton of carbon.

It is very clear that IAMs produce results that are very sensitive to assumptions, which is why they should be used with caution. Indeed, it is clear from the sensitivity analysis that in many respects we were cautious about, or omitted, many aspects of the modeling structure, which would have raised damages. There is certainly no justification in the claim that we systematically chose assumptions, which would give high damages.

It is very important to see the sequencing of the logic here. We start from the economics of risk, by emphasizing the importance of a quantitative stabilization target, in this case we identified a range. If this is no higher than 550ppm CO_2e, then there are strong implications for the emissions time path. Whilst there are some timing choices such a path should peak within 20 years and be below 30% relative to current levels (in absolute terms of 2050). We must be very clear on this. The role of the price mechanisms then become the decentralization of decisions to keep down costs around such an emissions path. In this sense the argument goes from quantities to decentralization prices. It does not, and should not start with the social cost of carbon (SCC). The SCC is a useful concept but is very sensitive to assumptions, indeed far more so than the stabilization target.

Research Questions on Costs and Damages

Many people will create their own models, building in risk and uncertainty in different ways, and with different approaches to ethics. What I think is particularly important is to put a lot more weight into understanding the probabilities and impacts of temperature increases and the tails of the distributions, either through using a more convex function for damages or through expanding the distributions—and we've got powerful evidence for thinking we have understated the spread. The relationship between temperature and damages is something that is a bit more speculative, but given the kinds of disruption that could occur at five, six, seven degrees Centigrade, I think that using a more convex damage function has considerable plausibility.

Other research questions needing further work include:

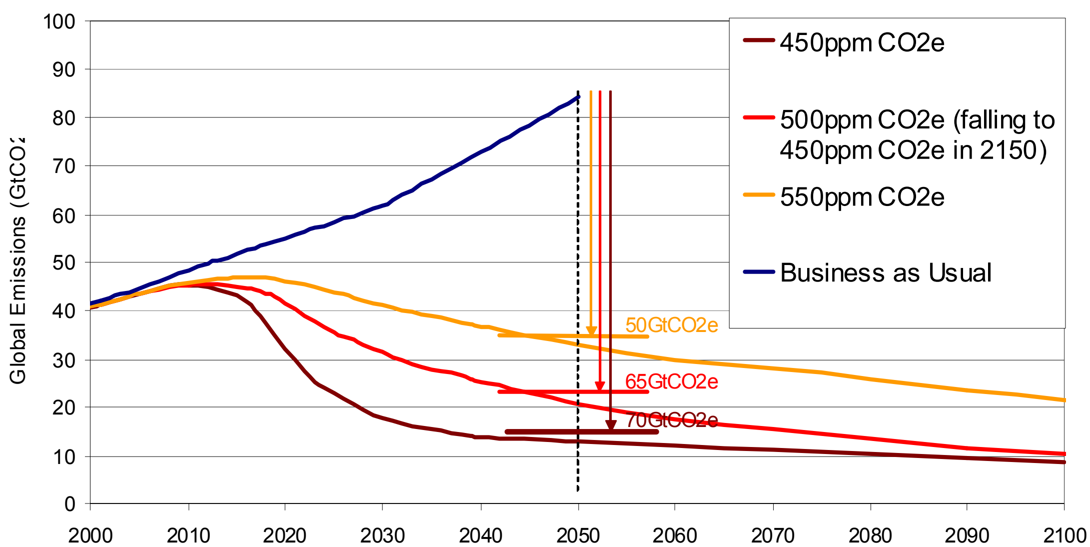
- Exploring ethics, including disentangling inter-temporal distribution, intra-generational distribution, and risk aversion. I think that using one parameter to represent all these things is much too crude.

- More detailed regional and sectoral analyses of both adaptation and mitigation. It is this detailed analysis of risks and action that should provide the basic underpinning for the analysis of action on climate change.

Policy Issues

Figure 9 emphasizes the urgency of action on climate change. The yellow line shows that if you adopt the target of stabilizing CO_2e concentrations at or below 550 ppm, then you should start cutting back, in absolute terms, the world's emissions in the next 20 years and keep them falling fairly steadily thereafter. To stabilize below 450ppm CO_2e would require emissions to peak by 2010, with a 6 – 10 %annual decline thereafter.

Figure 9: Emissions paths to stabilization



Many people are angry with us for even suggesting that 550 ppm is a sensible target; they would argue very strongly that 500 or even 450 is the maximum one should accept. They have a case and I gave the arguments on that before. All these targets clearly involve strong action.

Those that claim our implied action plans are too radical should be quite explicit that they would propose a path which goes considerably above 550 ppm CO_2e and would accept the corresponding risks involved. Unfortunately many have failed to be transparent on this by burying their arguments in the level of the carbon price.

What would be the costs of action to stabilize below 550 ppm CO_2e? We estimate the cost of a trajectory consistent with stabilization at 550 CO_2e to be 1% of GDP. We made our calculations in two ways: by surveying the results from the various macro models (suggesting a range of plus and minus 3%of GDP in 2050 around the central estimate of 1%), and by looking at the resource costs of particular kinds of technologies (suggesting a range of minus one to plus 3.5%of GDP in 2050). Shortly after we published these results, the International Energy Agency published a much more detailed study than we could possibly manage, whose cost estimate was slightly lower than ours (IEA, 2006). I think that one %is a reasonable ballpark for a 550 ppm CO_2e stabilization

Given the costs of the impacts of climate change, taking urgent action is good economics. If you compare the 1% estimate for the costs with the kinds of damage that I've been discussing, then taking strong action to stabilize at or below 550 ppm looks like a very good deal. It is hard to argue that a 1% increase, on average, in cost is going to make a big difference to the competitiveness of the United States or Europe versus China or India. Those are the kinds of cost differences that people absorb and just get on with during a growth process. And, of course, there will be opportunities, and there could even be Schumpeterian kinds of growth surges on the back of new technologies. There are potential important co-benefits associated with energy security, cleaner air and so on, as well.

The issues around estimating the costs of mitigation are set out in Chapter 9 and 10 of the Review. Time constraints do not permit me to elaborate these further in this lecture but I would like to emphasize our estimates are based on the existing mainstream literature and supported by our additional research.

Key Principles of Policy

Two-thirds of this lecture has been on costs and damages. More time would have allowed me to 'correct this imbalance'. The report is roughly 50-50 on costs–damages and policy and much of the more subtle and difficult economics lies in the policy analysis.
In considering policy we should be pricing for externality. That’s principle number one, basic, absolutely right, and terribly important. As well as proper pricing for carbon, we should be promoting research, development, and deployment. There’s also an important discussion to be had about behavior of individuals, firms and governments beyond simply the appropriate price incentives.

Carbon Pricing

Appropriate price signals for carbon can be established in different ways: greenhouse gas taxes, capping emissions and setting up a market in permits, or implicitly through regulation. In thinking about policy instruments we have to think about the risks. Here the risks of overshooting concentrations in the medium term are very high. Thus, the economics of risk points you to first thinking about stabilization stocks and then about the flows of emissions that are consistent with those stocks. Then as we think about managing adjustment costs, we go on to think about price mechanisms.

As we noted in the Review, taxation, emissions trading and regulation can all deliver a price signal for carbon.

Different countries will choose different combinations of these approaches for different sectors, reflecting their existing policy mix, histories, conditions and national politics. To take the case of taxes, they may be most useful in pricing carbon emissions from sectors that have a large number of small emission sources, which may also be mobile (such as road vehicles). In such sectors, the transaction costs for a large number of small emitters being involved in emissions trading schemes may be prohibitive.

In other sectors that have large, stationary sources of emissions (such as electricity generation or heavy industry), transaction costs for involvement in trading will be lower, making them more suited to using emissions markets. In many cases, these sectors are also competing internationally. Inclusion in an international trading scheme therefore helps to reduce any risks of differing carbon prices being imposed at the domestic level that have may impact on competitiveness. In theory, taxes could be harmonized across countries to prevent any competitiveness impacts, but experience in other policy areas shows this is very difficult to attain.

In terms of impacts on international co-operation, trading has the advantage that it opens up markets for emissions reductions across borders and therefore allows automatically for transfers of finance and investment between countries. Access to broad international markets is likely to allow firms to locate least-cost options for reductions and therefore keep compliance cost low. Where developing countries are involved in such markets, it therefore offers a channel for the financing of low carbon investments in these countries, which is particularly important for international co-operation on climate change. Again, in theory, carbon taxation could be used to transfer revenues across borders, but in practice this would be more difficult to achieve than through the direct, and largely private sector transactions that occur within an international emissions market.

Expanding and linking the growing number of emissions trading schemes around the world is a powerful way to promote cost-effective reductions in emissions and to bring forward action in developing countries: strong targets in rich countries could drive flows amounting to tens of billions of dollars each year to support the transition to low-carbon development paths in poorer parts of the world.

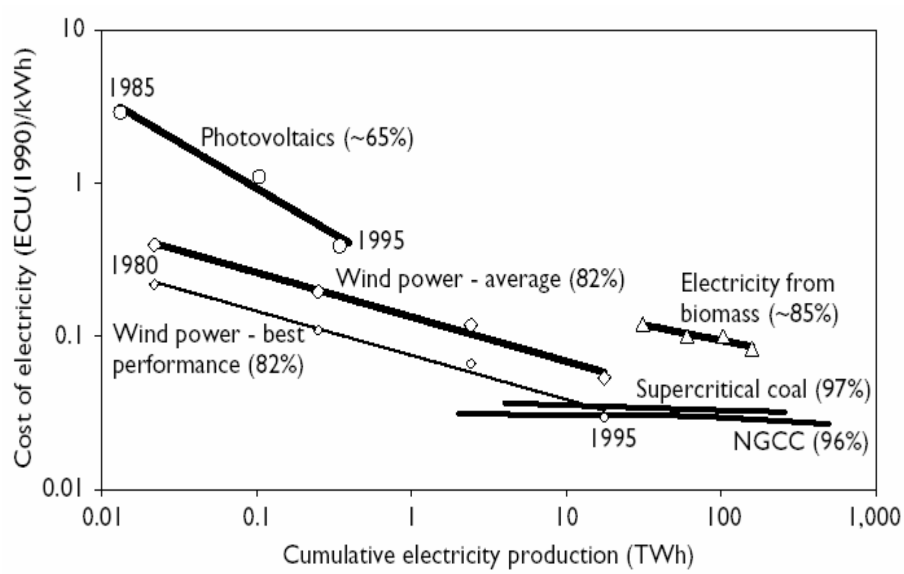
The economics of cost points to a need for short-run flexibility within sectors and countries. Policymakers and markets should be able to respond to new information on impacts and costs. Credibility, flexibility, and predictability are key if policy is to influence investment.

Research, Development, and Deployment

Some would say then that if you fix the price, if you fix the externality, there is nothing else to do; just let the markets work including for R&D, innovation and deployment. But I think that in the case of climate change this is misleading. For example, the markets would never be totally confident about a pricing policy based on the entire world acting together over the next few decades. So I think we have to go beyond that. And we know that in a world full of market imperfections and constraints on taxation, simply pricing for an externality in terms of marginal cost will not generally be the best policy.

One element of policy to promote technological change is public funding to support innovation in new technologies. Global public R&D in energy has been cut by half in the last 25 years or so. We can't say for sure what is the right level of global R&D, but such a large cutback doesn't sound sensible in relation to the climate trend. So, in the Review we suggest that R&D should at least be doubled, back to around $20 billion annually. Incentives for deployment should increase two to five times, from current levels of $34 billion. As Figure 10 shows, cumulative experience brings down costs. It is important to develop a portfolio of mitigation technologies, as this will reduce mitigation costs in the longer run. Governments must ensure that they provide adequate incentives to spur the development of what are likely to be the key technologies of the future such as carbon capture and storage for hydrocarbons. This is of particular importance for coal which is not only the most polluting hydrocarbon in relation to climate change but is also by far the most important source of energy for electricity generation, and is likely to remain so, for many countries including China and India.

Figure 10: Technology needs more than a carbon price (Source IEA, 2000)



Other Market Failures and Behaviour Change

People will want to discuss what responsible behavior is, just as they discuss what responsible behavior is on recycling, without necessarily being totally influenced in their choices only by the relevant prices and costs. And there's a discussion to be had about related market failures in buildings or landlord/tenant relationships, such as "Will you capture the cost of investment in insulation and so on?" There are other relevant kinds of market failures, particularly as regards energy efficiency.

As I've already emphasized, *responsible climate change policy* can be consistent with *growth* and *energy security*. If, but only if, we design our policies well, those things can be brought together. This is a crucial insight for policy and has begun to be very important in discussions on both sides of the Atlantic. Demonstrating this in greater detail at country and regional level will be crucial in taking policy forward.

International Action

Climate change is an international collective action problem. Such action requires a common understanding of the scale and nature of the problem. It also needs transparency and mutual understanding of actions. International institutions, including through their surveillance, can have a key role on of both these.

Partly this means being able to recognize what other countries are doing. For example, it is important to understand the advances in energy efficiency the Chinese are making in their 11th Five Year plan. Yet, they're still doing a lot of things that are very polluting, including the opening of 1 or 2 coal-fired electric power stations a week. But they're also doing a lot of things, such as reforestation, that go the other way. In China, we take care to explain what's going on in the U.S., and the U.S. is not inactive in this area, and in the U.S., we're keen to insist that China is doing quite a lot, too. Indeed, there are signs that most countries are starting to get to grips with the problem, including India in its 11th Five Year plan, which is starting this year. However, the scale of action in most countries is still far too low.

We should also be looking for trading structures that sustain cooperation by giving people gains from coming together. This is one of the great advantages of cap and trade.

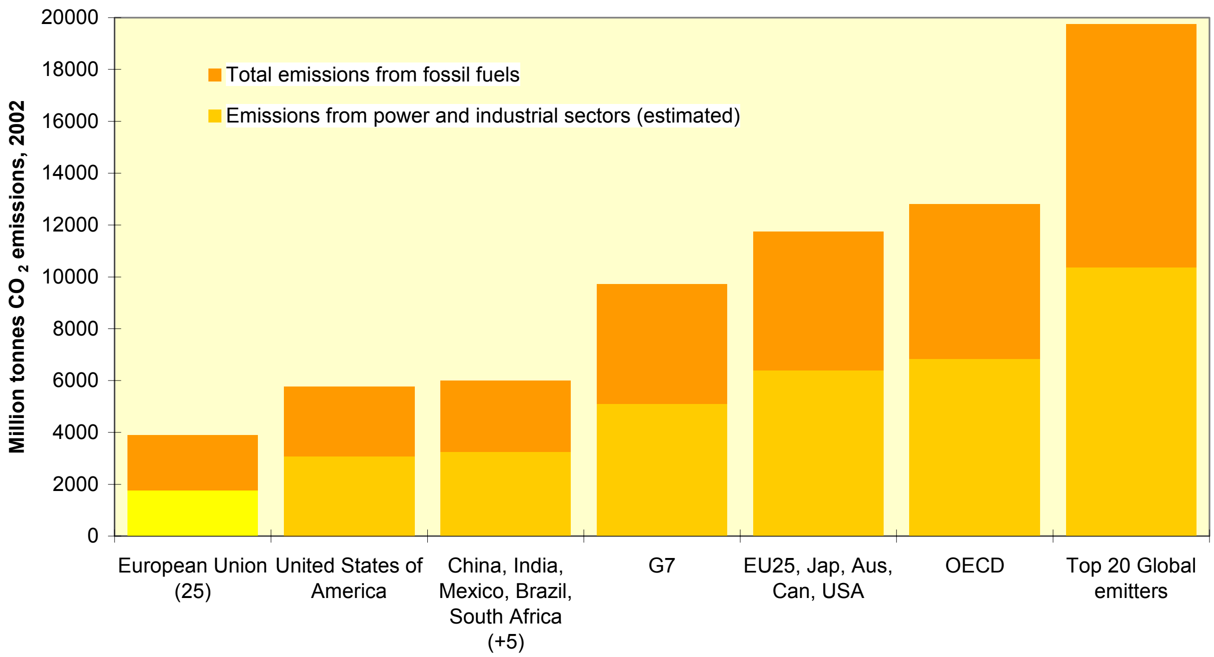
Trading structures must be equitable, too, because there's a very powerful feeling in the developing countries, which many of us would share, that "rich countries put those GHGs there and now they're telling us it's time to slow down our growth." Well, first we have to argue that growth doesn't need to slow down. You can move to low-carbon growth without necessarily slowing down. There will, however, be some associated costs, and it's only right that the rich countries take on the bulk of these costs given their historical responsibility, their wealth and their access to technology.

So, if the overall target should be at least a 30 %overall cut in emissions by 2050 on a global scale, the range of 60 to 90 %in rich countries seems about right from the equity point of view (see Part VI of the Review). That's California's 80 %, that's France's 75 %, that's the UK's 60 %, and so on. Effective international action needs to go ahead on several fronts: building carbon markets; deforestation; and adaptation, including through development aid, sharing of new technologies, and support for international public goods.

Building Carbon Markets

The demand side in world carbon markets comes from strong ambition in the rich countries. On the supply side in those markets we must try to identify more clearly than we've done up to now what constitutes an emissions reduction. We need better benchmarks, and we need stronger institutional structures to support these markets. Figure 11 shows how carbon markets could be scaled up from where we are now. In the bottom left-hand corner in the light yellow we have the existing European Union emissions trading scheme. The darker block on top shows the potential size if expanded to all sectors. Moving to the right shows how markets could be expanded if other regions were involved.

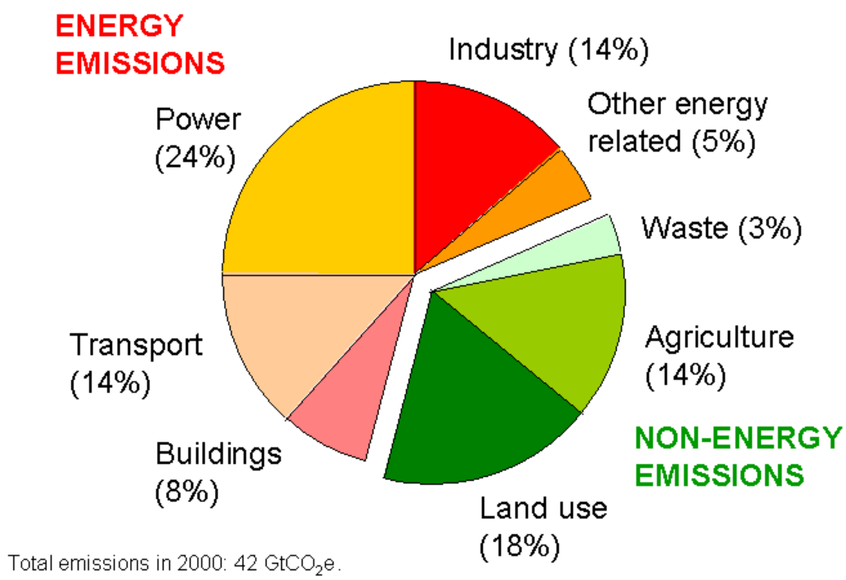
Figure 11: Possibilities for building international carbon markets



Deforestation

Figure 12 shows the need to look more broadly than just at electric power or transport. You have to look across the board at industry and buildings and, of course, land use where the key issue is deforestation. There's some dispute about the numbers, but deforestation currently looks to be a more important source of greenhouse gas emissions than transport. So moving ahead strongly to curb deforestation could be highly cost-effective and significant. Forest management should be shaped and led by the nation where the forest stands. Large-scale pilot schemes could explore alternative approaches for providing effective international support.

Figure 12: Sources of emissions, by sector



Actions on deforestation, as for any other sector, only take you part of the way. We are also going to have to look at energy efficiency in electric power, transport, buildings, industry, and so on. Reducing emissions wherever cheapest will minimize mitigation costs. So emissions should decline much more in some sectors where cheaper than others. Thus there are benefits from designing policy to ensure that there is a similar price in different sectors and regions. Increased energy efficiency and combating deforestation are the fastest and cheapest ways of reducing emissions in the short run.

Adaptation

Climate change will require costly adaptation in all countries. But adaptation to climate change will put strong pressure on developing countries' budgets and on development aid. Climate change adds to the complexity of decision-making about aid budgets, the productivity of aid, the need for aid, and the budgetary challenges of developing countries. If the environment gets more hostile, then the cost will rise of building bridges and railways and roads and irrigation systems to withstand the greater threats that they will face. We don't really know yet how much the extra cost will be, but it could be tens of billions a year for developing countries, and it surely underlines the arguments for delivering on the aid commitments that were made in Monterey in 2002, the European Union in 2005, and the Gleneagles G8 summit in 2005—especially when you couple it with the equity and the historical responsibility arguments on climate change. I did think of recommending more official development assistance in the Review, but having spent, with many others, 30 years doing that and seeing very strong promises in 2005 in the EU and at the G8, I decided we would just say, “The argument we gave you then was very powerful, and now it’s overwhelming, so deliver on your promises.”

International action also has a key role to play in supporting global public goods for adaptation. Many international public goods are relevant here, including more climate-resistant crops and technologies, and disaster responses. Weather and climate-change forecasting, of course, are of great importance in any kind of adaptation.

Research Questions for Policy

Research questions relevant for policy include:

- How to link and expand emissions trading schemes. There are lots of technicalities here that matter.

- How to develop and deploy carbon capture and other key technologies globally. For example, I have not emphasized carbon capture and storage of coal much in this talk, but, around the world, approximately a half of the electric power comes from coal. The proportion will be 70 %or more from coal in India and China for the next 20 or 30 years. Unless we get to grips with more efficient coal and carbon capture and storage for coal, we’ll be ignoring a big part of the problem. This is the only technology that we explicitly highlight in the Review. Otherwise, we suggest that countries should adopt the right kind of incentives, and see what kinds of technologies emerge.

- Planning for adaptation. Adaptation relies on a great deal of information about the challenges at the local level.

Conclusion

To sum up, the Review concludes that:

- Unless greenhouse gas emissions are curbed, climate change will bring high costs for human development, economies, and the environment. Concentrations of 550ppm CO_2e and above are associated with very high risks of serious economic impacts. Concentrations of 450ppm CO_2e or below will be extremely difficult to achieve, given where we are now and given current and foreseeable technology.

- The costs of mitigation are modest relative to the costs of inaction and strong mitigation is consistent with economic growth.
- Strong international action is urgent: delay means greater risks and higher costs. International action should be designed in a way that is equitable in the international division of responsibility—given the past history and the "common and differentiated responsibilities", in the language of Kyoto—and efficient, working through markets.
- Even with strong action to reduce greenhouse gas emissions, substantial adaptation is essential both for rich and poor countries.

The Review argues for using market mechanisms to address a market failure, taking into account risk in a very direct way when we think how to use those market mechanisms. Thus we should start with a stabilization goal, look at the path to stabilization, and then apply market mechanisms to different sectors and regions where market conditions vary and different incentives are important. R&D should be pushed forward for the usual kinds of arguments, but in this case, there's greater urgency and greater doubt as to whether price mechanisms alone are enough to achieve what's needed.

In the Review we suggest that initially the best path to reducing worldwide emissions is for individual economies in the rich world to take responsibility for strong reductions. If, as they are, California takes on the responsibility, and the EU takes on the responsibility, and they decide to see how they can trade emissions, markets will develop. It will be the insistence of the people of those countries and regions that their governments act responsibly that will be the enforcement mechanism. As individual countries follow their lead and build up their responsibilities, we could start to seek a stronger international treaty, but the world does not necessarily need some grand international enforcement mechanism. Though we certainly don't want to rule this out, it is quite hard to think how such enforcement would really work. But a treaty can be a very valuable signal of long-term international commitment, and I believe, on the basis of the foundations of commitments in individual countries and regions, that it will be a crucial element of international action.

Going back to the argument of why you'd want to stabilize emissions at 550 parts per million, and recognizing we're already at 430 parts per million and adding two-and-a-half parts per million a year and rising, then I think the case for urgent action is very powerful. The later we leave it, the more difficult it will be. The more you ramp up the stock of greenhouse gases in the atmosphere, the bigger the risks you run, and the tougher it will be to get to a sensible stabilization goal.

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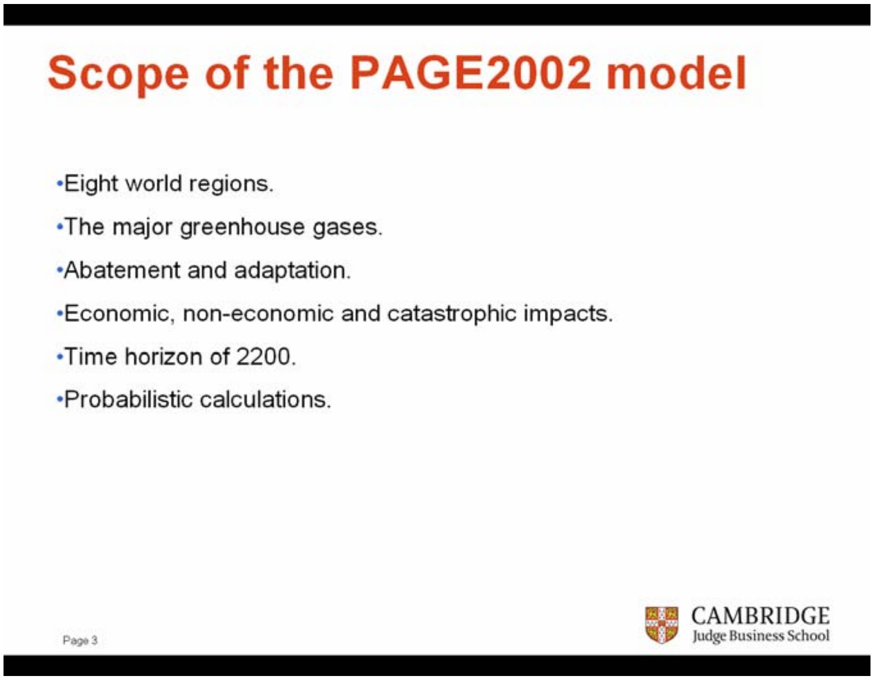
Chapter 2: Page Modeling System

Chris Hope

I'm going to talk about PAGE2002, which is the integrated assessment model used in The Stern Review, and to talk about what it can tell us about the social cost of carbon, which, as you know, is the impact of one more ton of carbon being put into the atmosphere now in the form of CO2. At the end I'll talk a little bit about some of the other things that the PAGE2002 model can do for us as we try and decide what to do about this serious problem.

I'm going to start with the structure of the model itself so you can see what's involved in it, talk a bit about the values that come out for the social cost of carbon in The Stern Review, and explain where those numbers come from. One of the advantages of the model is that it is transparent, and I want to make those numbers transparent to you so that we can understand where they've come from.

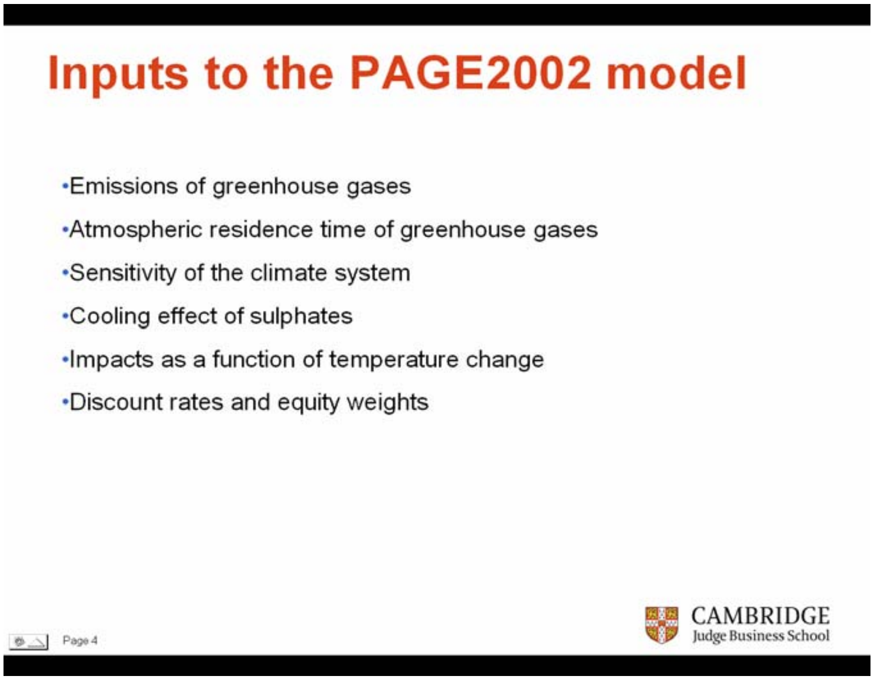
Then I'll lead into talking about what happens to the social cost of carbon, the impacts of a ton of carbon emitted as carbon dioxide, if we make some other assumptions based on some of the comments that have been made. This leads us into the discussion that we'll be having this afternoon. Then I'll talk for a few minutes about what else the PAGE2002 model can tell us.



So, very simply, the PAGE 2002 model is an integrated assessment model. It divides the world up into eight regions. It looks at all the major greenhouse gases, not just carbon dioxide. It allows you to make decisions about abatement, how you're going to cut back your emissions of gases, and adaptation, how you're going to cope with any impacts that might be caused.

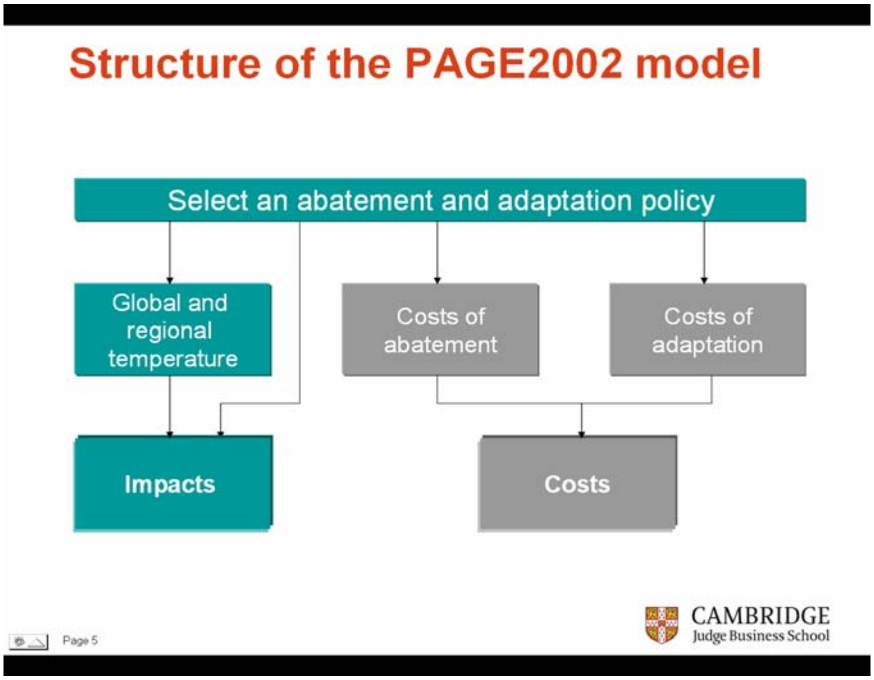
It looks at economic, non-economic, and catastrophic impacts, the kinds of things that we should be very worried about if we get temperature rises above four, five, six degrees Centigrade maybe. It has a time horizon out to 2200 because this is a hugely difficult and long-term problem.

And, most importantly, Sir Nicholas emphasized uncertainty all the way through his talk. All of the calculations in the model are done with a recognition of that uncertainty. So, they're done probabilistically. You don't just put in single values for parameters and get out single answers. You put in ranges for parameters and get out ranges for answers.

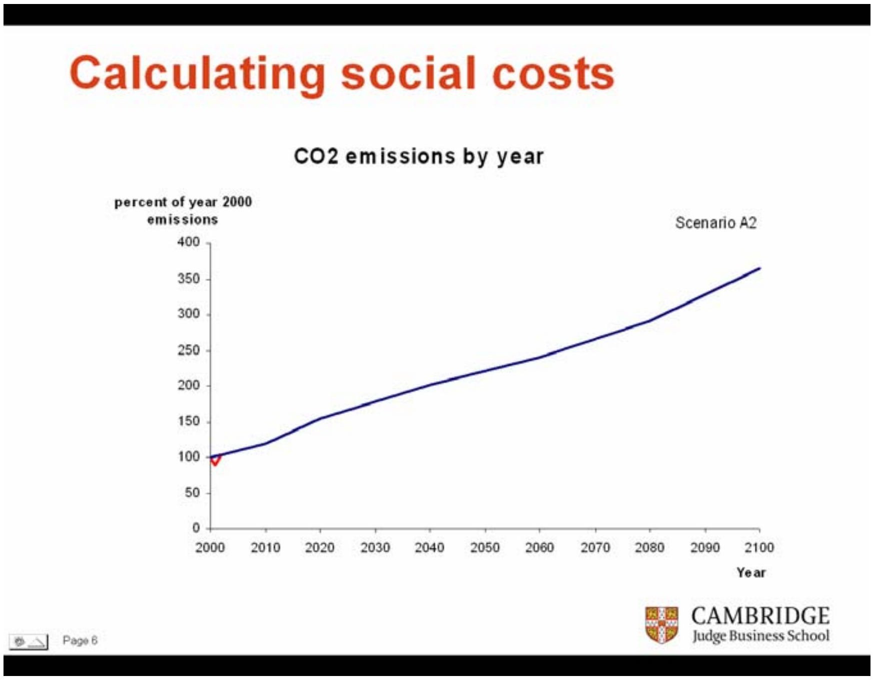


What kinds of things do you need to put into the model to be able to do these calculations? You need to have some projections of what the emissions of greenhouse gases are likely to be. You need to make some assumptions about the atmospheric residence time of the greenhouse gases. How long are they going to be up there? How sensitive is the climate system? Nick has shown a slide on the assumptions that are in there about that. You need to look at sulfates and the cooling effects of those.

So, this is sort of scientific information that needs to go into the model to be able to do the calculation, but also you need to look at impacts as a percent of GDP and how those vary as a function of the temperature changes, and you need to look at the discount rates and equity weights, the kind of economic parameters that Nick was talking about. This is what makes it an integrated assessment model. It puts in values from the scientific studies, values from the economic studies, brings them together, and allows us to say what kind of implications they have for the policies we might want to follow.



The structure of the model is that to run the model, you need to make some decisions about what your abatement and adaptation policy is going to be in all the different world regions, how much of each gas are you going to allow to be emitted, what kind of adaptation are you going to have. You can then calculate through on the left-hand side, shown in blue, which works out the global and regional temperatures that result from the emissions of the different gases. And if we look at the amount of adaptation, that can then, in combination with the temperatures, tell us what the impacts are likely to be. I won't talk very much about the things on the right-hand side of the model, which allows us also to say what are the costs of adaptation, what are the costs of abatement, and get the costs of taking action as well, but I will refer to that at the end.



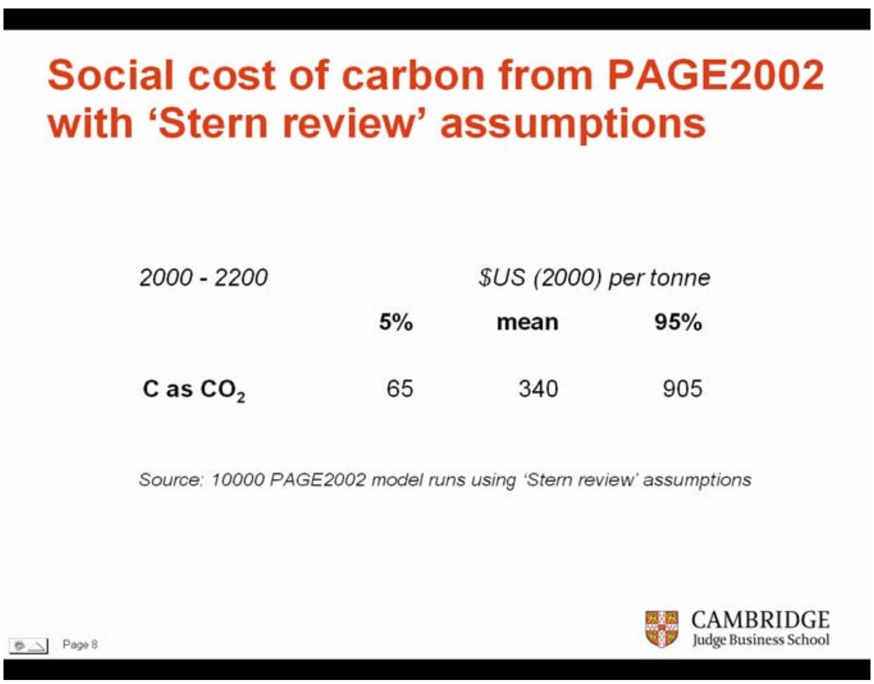
So, what do you actually do if you want to work out the social costs of a greenhouse gas, in this case, carbon dioxide? Here's a slide showing what the emissions might be over time. Under scenario A2, one of the IPCC scenarios, you can use the model to calculate in each region in each time period what the impacts are likely to be in a probabilistic sense for those emissions, and then you can aggregate them up over the regions and aggregate them back through time and aggregate them across the different outcomes, as Nick was talking about, to give an estimate of what the total impacts are likely to be if you have emissions along that blue line there.

And then you can do exactly the same thing with emissions just the same as along the blue line except for that tiny red triangle taken off at the beginning, and you can work through again all the impacts that there will be in the different regions over time over the different outcomes with that scenario exactly the same, except for that little red triangle there, and then you can take away one from the other.

And as that little red triangle actually represents one billion tons of carbon, if you then divide the difference between the two scenarios by one billion, that will then tell you how much extra impact is being caused by one ton of carbon being emitted today. And that's the way these kinds of calculations are done to work out the social costs of the marginal impacts.

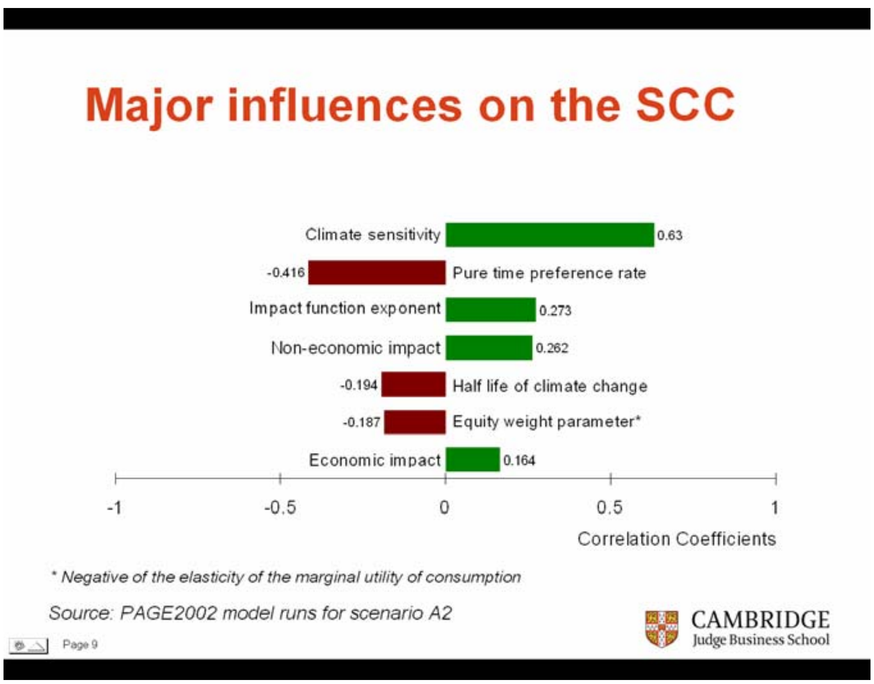
So, what kinds of figures do we get from The Stern Review? The number for the social cost of carbon that is most prominent in the review, a figure of $85 per ton of CO2, translates to $312 per ton of carbon, which is the more usual unit that people measure it in. As Nick said, this is being calculated using the PAGE 2002 model with sets of assumptions in there and transforming the answers using balanced growth equivalents and so on afterwards in order to be able to produce this expected value number.

Now, the first thing we can do with the model is say, well, okay, let's make all the assumptions exactly the same as in The Stern Review and let’s rather than just produce one number, the central number, let's see what kind of range of numbers comes out of the model. And this is what's shown on this slide.



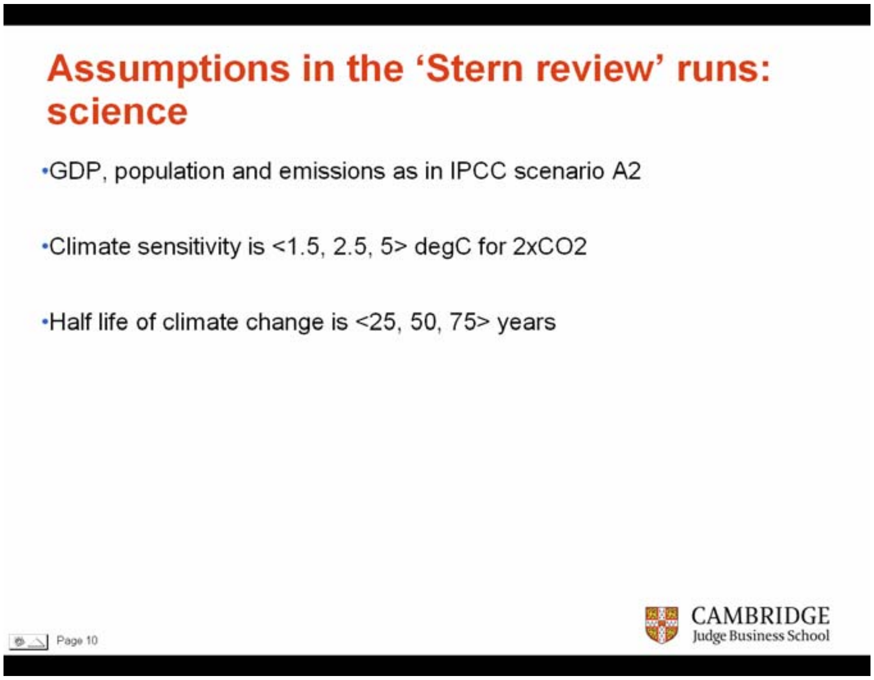
I've put ‘Stern Review’ here because this isn't the answer using the clever balanced growth equivalent mechanism that Nick and his team have been able to do. This is the answer just taking the numbers in terms of the effect on GDP, transformed using equity weights, and you can see that we can end up reproducing the answers from the Stern Review pretty closely. The mean value that comes out of the model when you run it like that is $340, just a bit higher than the central number produced in the Stern Review, and the five to 95% range is $65 to $900 per ton of carbon.

So, immediately you see just how uncertain we are about this. Even using all the parameters pretty much exactly the same as in the Stern Review, we end up with a 90 %confidence interval for the social cost of carbon that is an order of magnitude, or a bit higher. One of the advantages of having a probabilistic model like PAGE is that you can immediately get out of it some information about which of all the uncertain inputs there are in the model have the biggest effects on the answer that you're getting out. In this case, the answer for the social cost of carbon. And we can see from the next slide that it's a mixture of the scientific information and the economic information that goes in there.



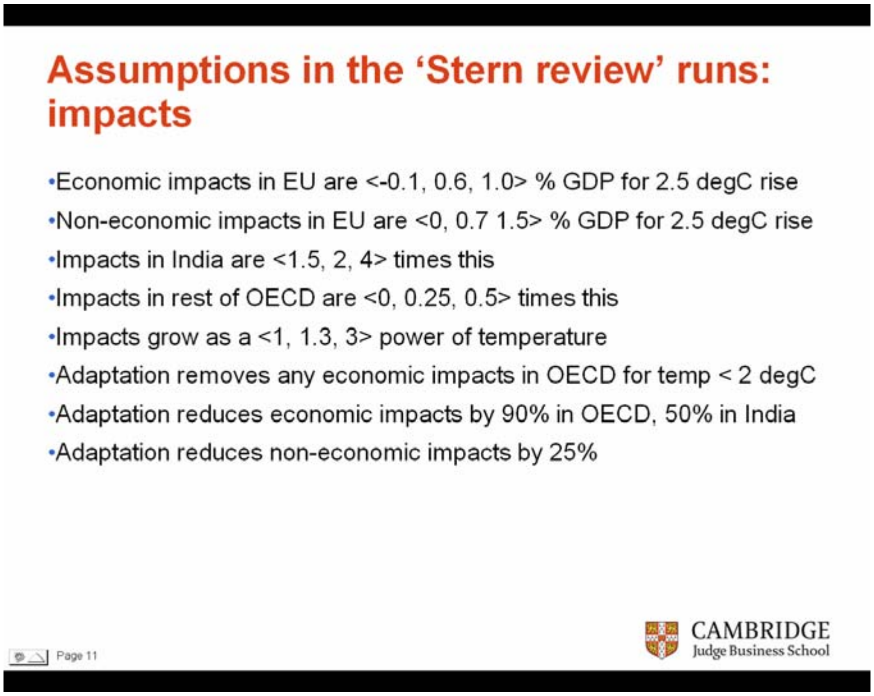
The most important parameter, the one with the longest line here, is the climate sensitivity. Our uncertainty about that has the biggest impact on the answer we get for the social cost of carbon. The next most important is the pure time preference rate that you assume and so on down. The third one is the impact function exponent that Nick spent some time talking about as being an important parameter, and we can see from this slide that it is one of the top parameters here.

So, this slide tells me which parameters I need to tell you about to get you to understand why the answers in the Stern Review come out as they did.



The assumptions in the Stern Review runs, which ended up with that range of social cost of carbon that I showed a moment ago, are these: The GDP, the population, and the emissions are as in the IPCC scenario A2. Climate sensitivity has a range somewhere between 1.5 and five degrees Centigrade for a doubling of CO2 concentrations, with a most likely value of 2.5 degrees. The little triangles around the numbers show this is a triangular distribution with the bottom point being the minimum, the top one being the maximum, and the middle number being the most likely input.

So, as Nick said, this is a very standard assumption about climate sensitivity, standard assumptions about the half-life of climate change, how long it takes on average for the earth to respond to any change in forcing of between 25 and 75 years.

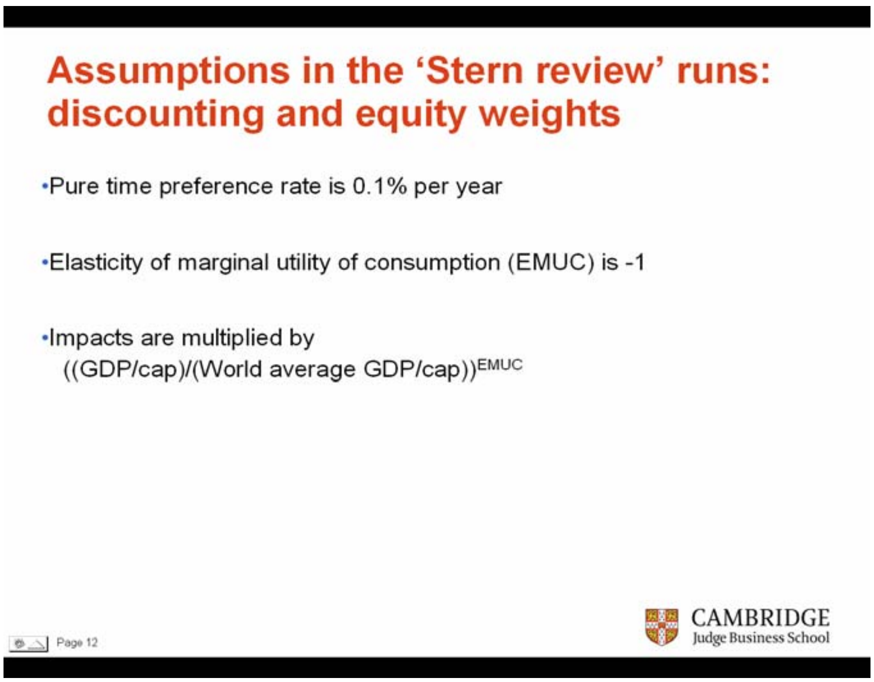


The impact inputs. The economic impacts in the European Union in the model in The Stern Review runs are assumed to be somewhere between minus 0.1% to plus 1% of GDP for a two-and-a-half degree Centigrade rise. In other words, the model does allow a small possibility that global warming could actually be a good thing, could lead to benefits rather than costs in regions like the European Union.

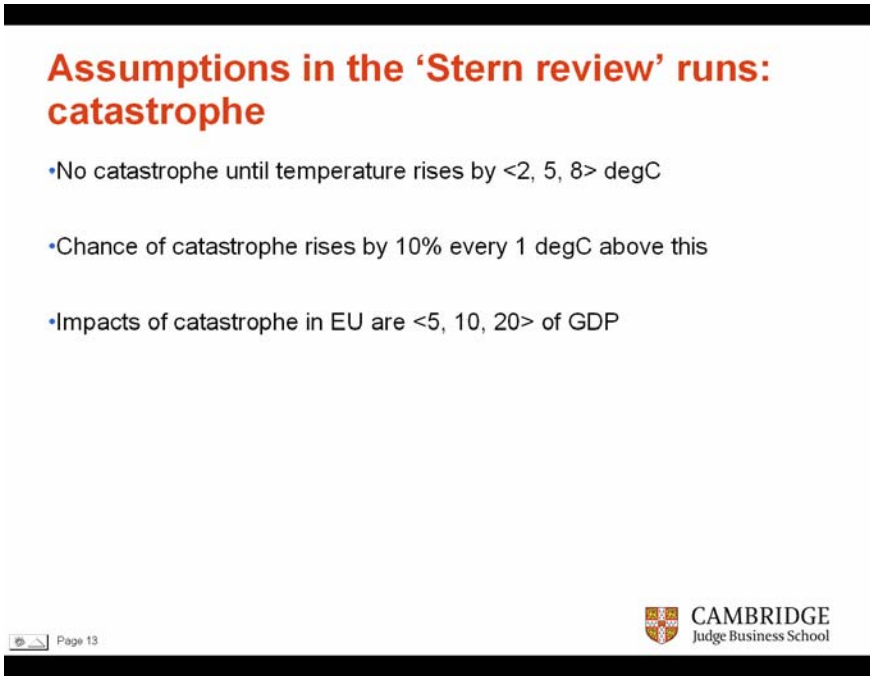
However, the non-economic impacts, the effects on health, the effects of inundation of wetlands and so on that don't get directly into GDP, are assumed to be somewhere between zero and 1.5% of GDP for a two-and-a-half degree Centigrade rise.

Now, the impacts in India or other poor countries are greater than this. There's a multiplicative factor that's maybe twice as high in terms of percent of GDP lost. On the other hand, the impacts in the rest of the OECD are smaller than in the EU, because in Europe the coastlines are long and coastlines are quite vulnerable to things like sea level rise. Other assumptions are made about how impacts vary as the power of temperature. Well, here they are. The power function is somewhere between linear and cubic in temperature, with the most likely just slightly more than linear in temperature. As temperature goes up, impacts go up to the 1.3 power of temperature.

There are some fairly aggressive assumptions about adaptation in the model. Adaptation is assumed to remove any economic impacts in the OECD for up to a two degrees centigrade temperature rise. It's perfectly adapted to temperatures up to that level. If we go beyond that, it's assumed that adaptation can reduce impacts 90% compared to what they're stated as in the first line of the slide. Adaptation is not so effective in poor countries, but it still reduces economic impacts by 50%. The non-economic impacts can only be reduced by 25% because it is not to see how we might be able to prevent things like the inundation of wetland.

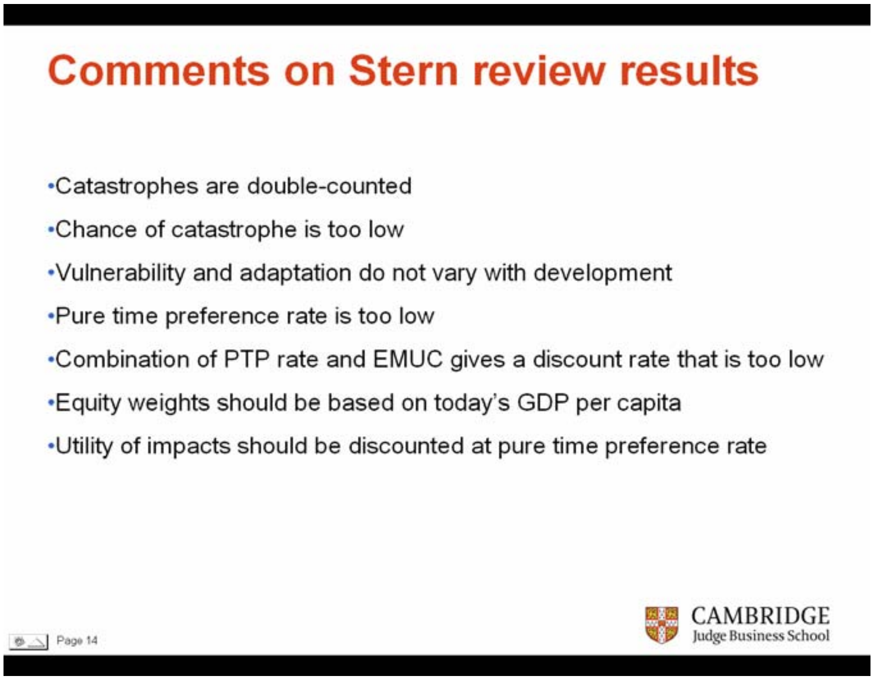


The discounting assumptions are the ones that have attracted most comment and Nick has talked about the pure time reference rate in these runs of 0.1% a year. The elasticity of marginal utility of consumption is the same thing as Nick's eta parameter, set at minus one and the equity weights are applied by multiplying the impacts in each region by that equation at the bottom. The effect of that equation is that a dollar's worth of impacts in a poor country is valued at more than a dollar's worth of impact in a rich country.

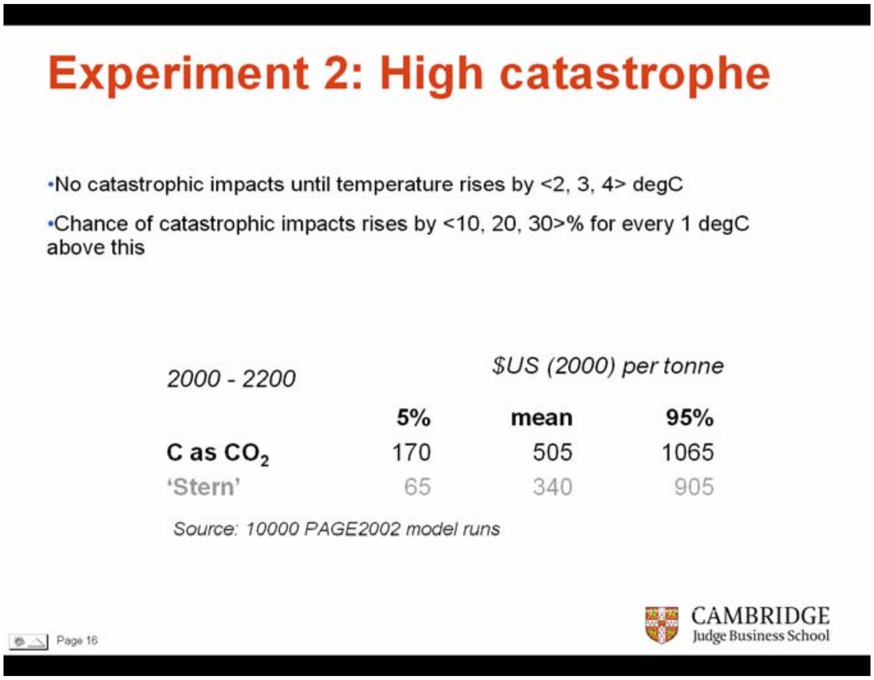


Finally I want to show you what kind of assumptions are made about the possibility of catastrophe. Catastrophic impacts are things like the melting of the West Antarctic ice sheet, and are what many people are most worried about in the long term. It's assumed there's no chance of this kind of catastrophe if the temperature stays below about five degrees with a range of two to eight degrees above pre-industrial levels. If you do get above that threshold, the chance of a catastrophe rises by ten %for every degree centigrade. And if we do get a catastrophe, that's quite severe; in the EU you lose between 5 and 20% of your GDP, with a most likely loss of ten percent.

So they're the main inputs to the model. If you use these inputs, and I don't think they're outrageous or outside the range of numbers that come from the literature, you will end up with a social cost of carbon of about $300 dollars per ton with a range of maybe $60 to $900 a ton. It's just a consequence of the inputs. Of course, if you don't think those inputs are right, then you will end up with a different social cost of carbon and therefore different implications for what you might do. What I'm going to do is just run through a few changes that you might make to the input numbers and see what effect they have on the social cost of carbon.



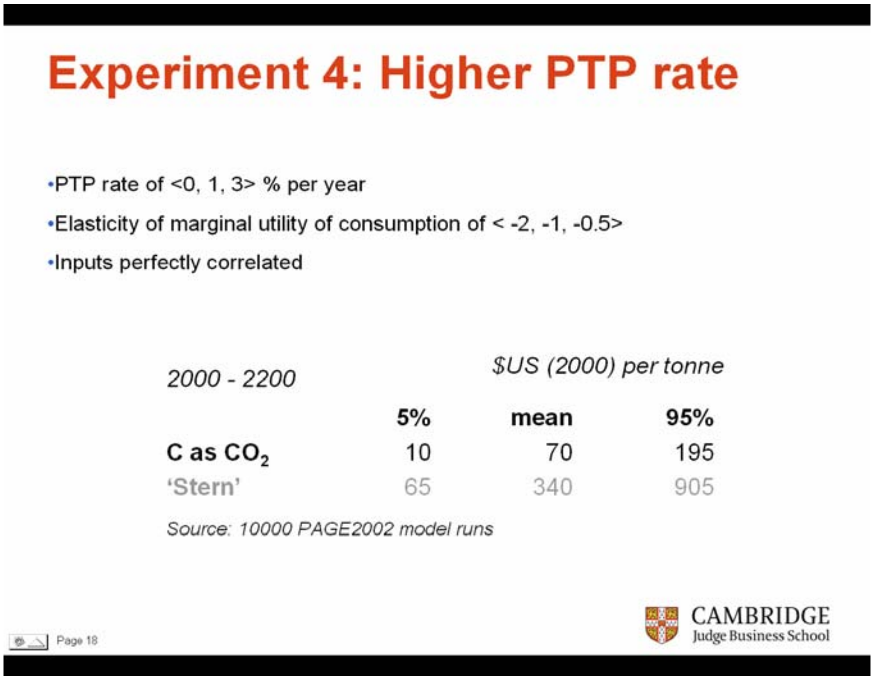
So, the kinds of comments that there have been—and this leads into this afternoon's discussion—on the results are, well, maybe this estimate of catastrophe that we've got in the model is not quite right. Maybe it should be either lower or higher, and maybe the assumptions we've made about pure time preference rate and the elasticity of the marginal utility of consumption are wrong; they end up giving you a discount rate that's lower than we observe in the market place.



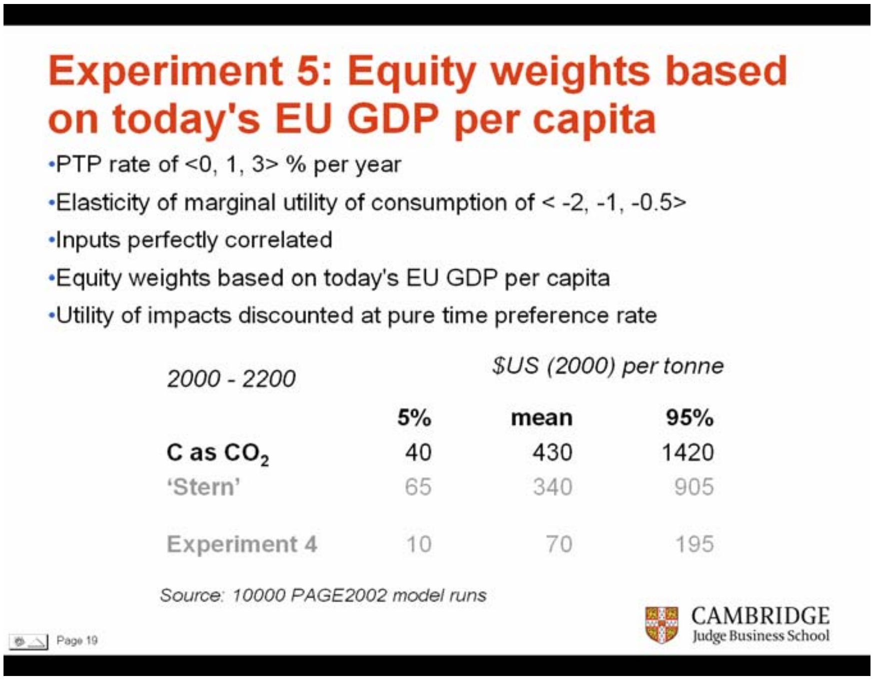
The assumptions that we made for catastrophe in the Stern Review runs end up giving you maybe a 2 ½ % chance there's a catastrophe by 2100 and a 25 % chance that there's a catastrophe by 2200. Some people have said, actually, it's more likely than that.

Here are some parameters which try and take that into account. If instead of saying we can't have any catastrophe until the temperature rises by five degrees, we say, well, maybe we could start having a possibility of a catastrophe if it goes above three degrees with a range of two to four, and if the chance of a catastrophic impact rises not by 10 % for every one degree centigrade above this but by 20%, then we end up with values for the social cost of carbon about 50 % higher. $500 is the most likely value rather than $340.

Even though—even with these new values for a higher possibility of a catastrophe, there's still only about a 25% chance that you'll have one by 2100 and about an 80 %chance you'll have one by 2200. So, you're talking about things that are most likely to occur in the 22nd century, over a hundred years from now, and yet they still have quite a big effect on the social cost of carbon today.



What happens if you take a different ethical position from Nick and his team? What happens if you assume that the pure time preference rate is a bit higher, maybe somewhere in the range of zero to 3% a year, most likely one percent? And what happens if you assume the elasticity of marginal utility of consumption again has a range going up to minus two, the kind of number that Nick was talking about and maybe down to minus 0.5? And what happens if you assume those inputs are perfectly correlated so that you end up with the kinds of consumption discount rates of the order of 4 % a year that we tend to see in the economy as a whole? Well, the answer then is if you use exactly the same scheme for doing equity weighting and discounting, you end up with a social cost of carbon that's about four-fifths lower. The mean value goes down to about $70 per ton of carbon and the range from ten to about $200.

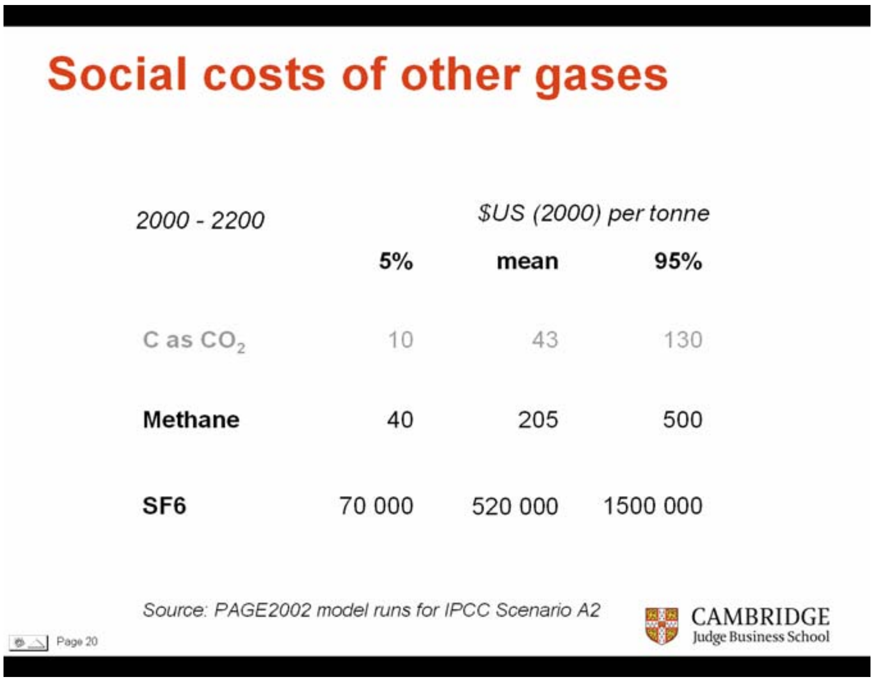


But that's not really the end of the story because if you were wanting to use this kind of experiment about higher pure time preference rates and range for the elasticity of marginal utility of consumption, you would probably want to go the whole hog and do the kinds of different runs that a lot of economists have suggested we should do, where you base equity rates not on the world average GDP per capita in a particular year, but you base them on today's EU GDP per capita, and you then discount your utility impacts not at the consumption discount rate but just at the pure time preference rate.

And if you do that, and keep everything else exactly the same as experiment 4 which I just showed you, the mean value not only comes back up from $70 per ton of carbon back up to $300, but it actually goes higher, to a mean value of about $430 per ton of carbon.

So, there's clearly a lot to be discussed—and I know we're going to discuss this more this afternoon, and that will be good because one of the advantages of having a model like this around is that when you get different views on what should be put in for different parameters, the model's there, you're able to run them through and see what implications they have for the social cost of carbon and, therefore, the policy that you should take.

What I'm going to do now is just run through in the last three or four minutes some other things that you can get out of this kind of integrated assessment model. These are results that come from runs done before the Stern Review. So, typically, with higher pure time preference rates than the 0.1 %per year that Nick's team has used and, therefore, the social cost of carbon that you get from those kinds of runs might be down around $40 as a mean value.


Social costs of other gases

2000 - 2200		$US (2000) per tonne	
	5%	mean	95%
C as CO_2	10	43	130
Methane	40	205	500
SF6	70 000	520 000	1500 000

Source: PAGE2002 model runs for IPCC Scenario A2

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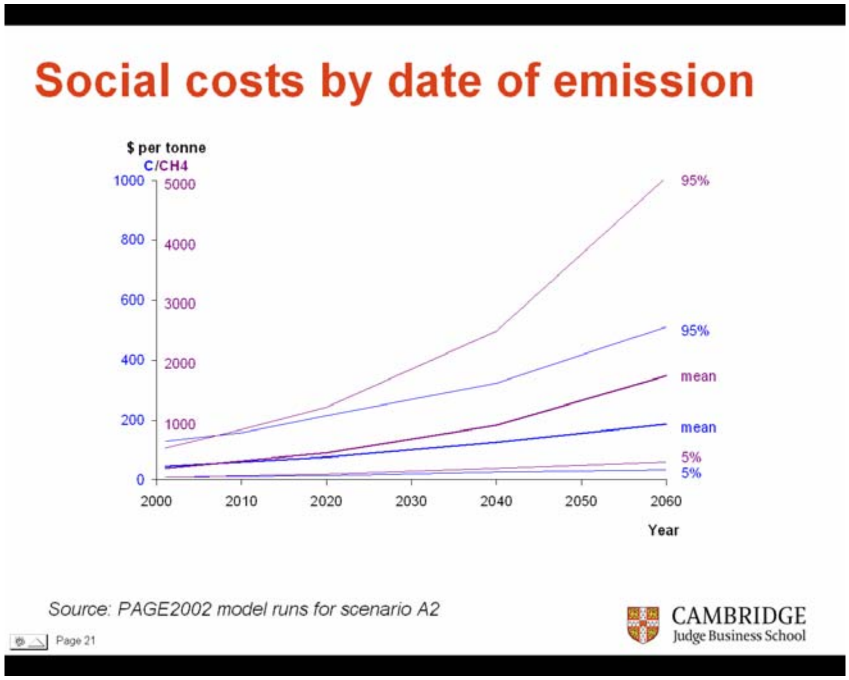
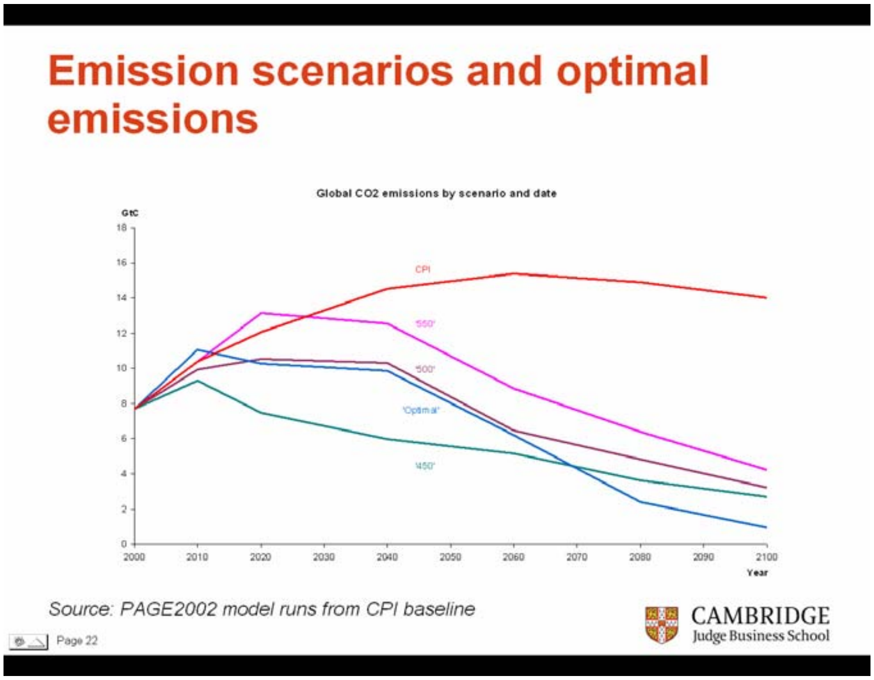
Because you're putting all the other greenhouse gases in the model as well, you can work out what's the social cost of the other greenhouse gases, too. You can work out how much emphasis you should be placing on reducing methane, reducing sulfurhexafluoride, or the other gases compared to reducing carbon. If we're going to solve this problem, we're not going to just do it by tackling carbon dioxide alone. We're going to have to tackle the other greenhouse gases as well.



The model can also tell you if you take that little red triangle of emissions away—not in the base year today, but at some point like 2010 or 2020 or 2040—what happens to the social cost of carbon over time and the social cost of other greenhouse gases over time. And here we can see in blue the values for what happens to the social cost of carbon over time and in purple what happens to the social cost of methane over time, and the scales are calibrated such that they look equal in the base year today.

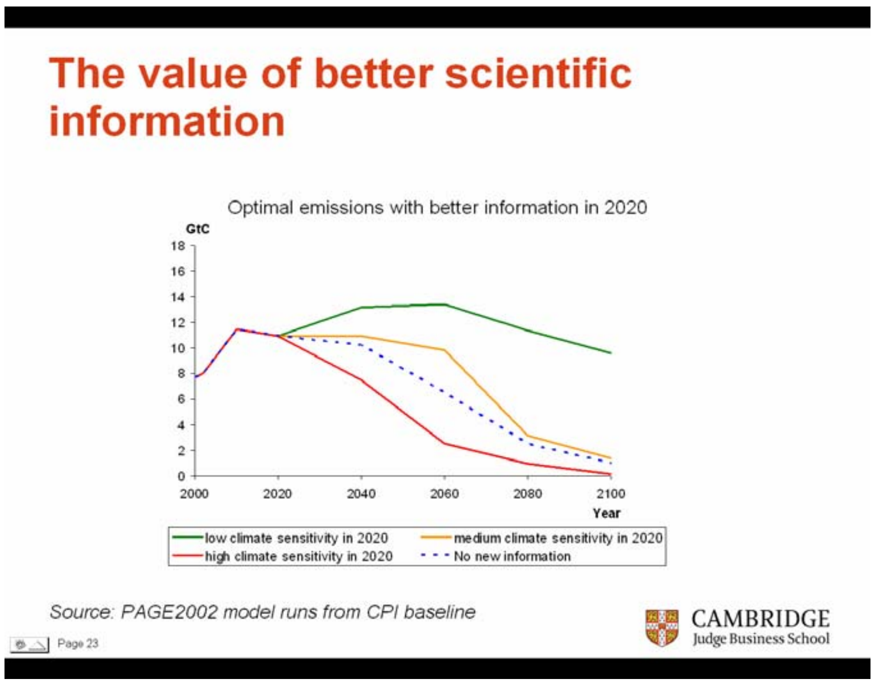
And you can see that what happens is that they both increase over time. They increase because as we get closer to the time when you would expect the most severe impacts of climate change to occur, then the extra impact that you'll get from putting another ton into the atmosphere gets higher. The mean value for the social cost of carbon goes up at about 2 ½ % a year. The mean value for the social cost of methane goes up more than that at over 3 % a year, and that's to do with the different lifetimes of the different gases in the atmosphere. I can explain it in the discussion if people want to know more about it. So, that's another thing you can do.



We need to think not just what should be used for the social cost today, which might set us a carbon price or a methane price today, but how is that going to have to change over the future as we carry on with this policy that's going to have to be there for decades if we're going to make any impact on this. If you remember the slide showing the structure of PAGE that I had right at the beginning and say, okay, let's look at the costs of doing something about this problem, the cost of adaptation and the cost of abatement, as well as the impacts, you can add those two things together. You can add together the total impacts that are left from climate change and the cost of doing something about the problem, and you can then begin to say, okay, what kind of policies can we put in place that will try and minimize those costs, again aggregated over space and time and all the different outcomes in a probabilistic way, and you end up perhaps with some lines like that blue optimal line on the graph.

That's the sort of set of policies that might end up minimizing the sum of the action cost, the cost of doing something about the problem, and the impact cost, the cost of climate change as a whole. And you see that even with much lower values for social cost of carbon than we get in the Stern Review, those kind of optimal policies are likely to end up leading you down to quite low emissions as we go further into the future.

And if you have that, if you can do something clever with genetic-algorithm-type methods which allow you to work out an optimal path of emissions even under uncertainty, then you can do something which is really quite valuable for the research community as well and say, okay, that's our optimal path if we don't know any more about the problem. If we've got this huge uncertainty that we have at the moment, it's the blue dotted line there.

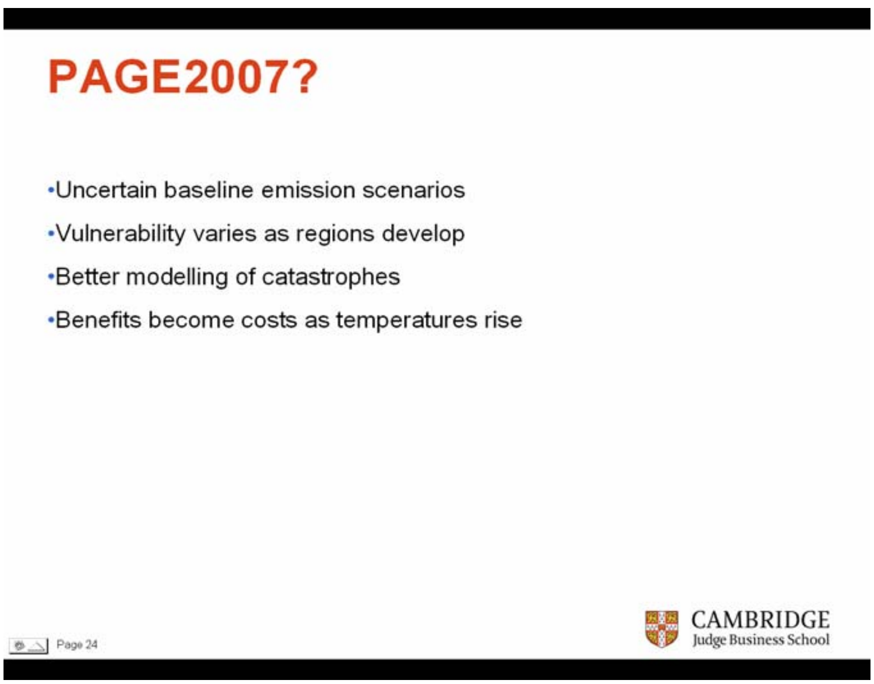


What happens if we get some better information in, say, 2010, or in 2020? Well, this slide shows what happens if we get better information about the climate sensitivity, this very important scientific parameter, not that we get perfect information, we know exactly what it is in 2020, but it's just a bit better. We reduce the range by about half compared to what it is today.

Obviously, if you get information that the climate sensitivity is towards the low end of the range, then the optimal emissions will be higher, the green line there. If you get information that the climate sensitivity is towards the high end of the range, the red line, your optimal emissions will end up being lower. And by looking at the total cost of impacts and costs of taking action once we've got this better information, you can work out what the value of this information is to you.

It actually turns out that the value of this information is enormously high. If we get information that halves the range of our climate sensitivity parameter in 2010, that's worth about 400 billion dollars to us. If we get that information in 2020, it's worth about 300 billion dollars to us, not quite as much because we aren't able to take action quite so early.

But that gives you a huge impetus for thinking about what kind of research you should be doing and how much you should be spending on these kinds of scientific and economic studies that we need to do. It also, of course, assumes that people take notice of them and will adjust their emissions optimally as a result of them, but, you know, we all have to make some kind of assumption there.



So, that's it really. What I've tried to do is be as transparent and open as I can about what goes into this model that's at the heart of the review, calculating these kind of numbers, show that the numbers that are in there are not outrageous, they're fairly standard, and what happens if you change some of them. Of course, the model isn't perfect. It carries on being developed. As the new IPCC results come out this year, we'll want to have new versions of it and keep it going.

If anybody has any questions about what I've run through here or would like to think about using the model themselves to run through their own assumptions that they might have, which might be different from the ones I've shown here, well, that's the great advantage of having the model there. It means we can do that kind of run and see what different assumptions do to the policies we would want to adopt, and I'd be very happy to work with anybody who might want to do that.

Chapter 3: Question and Answer

MEMBER OF THE AUDIENCE:

This is a question of clarification for Chris Hope about the treatment of uncertainty. As I understand it, the probability distributions that you are drawing for outcomes start from a range of values for each of the parameters that go into the model. So you have a joint distribution of values for the parameters, and depending upon how the joint distributions interact in the model, you generate the distribution of outcomes. So you are not working with uncertainty per se, with the distribution of outcomes in a probabilistic sense, but rather with the distribution of simulations, if I understand you correctly.

It's true that you don't have enough information to put together a joint distribution, but why not start with some prior distribution and, as the information comes in, update the prior distribution and see what sort of outcome probability a distribution of outcomes generates?

CHRIS HOPE:

For each of the different parameters we try to define uncertainty ranges that reflect those in the literature or in research. That's why we have a range of one-and-a-half to five degrees for climate sensitivity, for example. Then we run these ranges as joint probability distributions all the way through the model. From 10,000 runs of the model, we pick from each of these joint probability distributions for the inputs and build up a probability distribution for the output.

Most of the time you want to design your models so that the inputs are independent of one another. But sometimes you have to deal with input correlations. You can the PAGE model with correlated input distributions and work out what the output distribution is.

And, as my last slides showed, you can then talk about what happens if you get better information at some point in the future and you do some hedging strategy up to there, and then when we get better information, we split the strategies up according to that information. That can tell you something about how much that information is worth to you. Those slides only showed the value of information for a scientific parameter—climate sensitivity—but obviously, it would be nice to also model the value of extra information for things like the impact function exponent.

MEMBER OF THE AUDIENCE:

How useful, and significant in your analysis, are policies that accelerate the demographic transition?

NICHOLAS STERN:

Policies that accelerate the demographic transition are valuable in their own right. I think we understand that what helps drive the transition is policies that make good sense to follow anyway: promotion of human rights, promotion of economic development, job opportunities for women, education for girls and women, access to reproductive health services. Those are the kinds of things we know from looking at the way in which fertility rates have dropped, say, in Bangladesh from six to three over the last 25 or 30 years.

Such policies would help, of course, to mitigate global warming, but I wouldn't particularly want to go that route in arguing for them: I'd want to argue for them in their own right.

MEMBER OF THE AUDIENCE:

This is another clarifying question. How reduced-form is your model? Do you actually try to trace out the future of energy consumption and pinpoint when the transition from oil to coal is taking place, and so on? Do you estimate how much the temperature is going to rise on the basis of exactly which technology is being used at which time? Or do you just make an assumption about how fast the temperature is going to rise and an assumption about how costly it is if the temperature rises?

CHRIS HOPE:

It's a very reduced form model. We do not explicitly model the energy sectors, the use of the different fuels, and so on; we start at the point of saying what the emissions of the different greenhouse gases are. So, we need to feed into the model what the emissions are predicted to be of CO_2, methane, sulfurhexafluoride, and the other gases that are important in causing climate change. From there, we can work out what's going to happen to the concentrations, the forcing, the temperature, all the while bringing in the chain of uncertainties that Sir Nicholas has been talking about, and work through to the impacts at the end and the uncertainties there.

So, PAGE doesn't have an explicit energy model on the front of it. It would be nice to have one. But since the Inter-Governmental Panel on Climate Change (IPCC) has already done a lot of work to build up the emission pathway, and provided this readymade for us to use, I decided that making our own explicit energy model wasn't the best way of using our effort.

NICHOLAS STERN:

On the cost side, in thinking about how to start to control the emissions and get them to peak in 20 years time and gradually come down, we did look at the implications of different kinds of technologies and when they might come into use. In that kind of analysis you do get the different balance of energy use from different technologies, but it's not integrated into the full model.

My own view on these models is that at some point you've got to try to stop loading lots of things in. On the whole we looked at the cost side separately from the overall modeling, to allow us to get involved in much more detail than could be handled in the full model.

MEMBER OF THE AUDIENCE:

Regarding the PAGE model, I'm curious about the choice of the A2 scenario as used in the Stern Review. I know that a number of the assumptions used in this scenario—particularly about population but also about economic growth rates—may become somewhat problematic, especially if you extend the model out to the year 2200. I'm curious if you've tried running the PAGE model with, say, the A1F or A1B scenarios and if so, how that changes the outcomes.

CHRIS HOPE:

One reason why we used the A2 scenario was that this is one of only two scenarios in the third IPCC report that has some probabilistic information on it. There were several runs in the report which you could use to understand the range of answers that might come out if you use that scenario.. The other scenario that the third IPCC report described in that kind of detail was scenario B2, and I've done quite a lot of runs with that as well. A third scenario, elaborated since the third IPCC report, is the common POLES-IMAGE scenario: business as usual.

You can run whatever you like as your business-as-usual scenario, add some assumptions about uncertainty, and then see what impact that has on the answer. One of our interesting results is that the social cost of carbon doesn't vary much depending on which scenario you impose it on.

NICHOLAS STERN:

The assumption made about population does matter for the balanced growth equivalent. There is quite a heavy population load in the A2-1 scenario. So we did some back-of-envelope sensitivity analysis to see what difference working with smaller population numbers might make, given the same kinds of emissions. This showed that with smaller population, the environmental damage is somewhat less.

MEMBER OF THE AUDIENCE:

An issue for policymakers is whether the appropriate social cost of carbon to use in policymaking is the business-as-usual social cost of carbon or the significantly lower social cost of carbon that is associated with a stabilization trajectory to 550 parts per million (ppm) of CO_2 equivalent? What are your thoughts on that?

NICHOLAS STERN:

Any shout-out price, which is a marginal concept of course, is problematic in a modeling structure where you're dealing with (in the model itself) very big non-marginal effects and if further you're dealing with policies which themselves could make very big differences. This means that you have to be very careful to attach to any estimate of the social cost of carbon a statement about the kind of path to which it corresponds.

Here Chris Hope was very explicit. His social cost of carbon attaches to the business-as-usual path. So, suppose you take the business-as-usual path with these rising emissions and you perturb it a little bit at a given point in time. What happens to the subsequent path, and then the difference between the two, is the damage caused by the extra carbon.

With a path that is more sensible than business as usual, and entails controlling emissions into the future to stabilize at 550 ppm, the social cost of carbon will be lower because the stocks of emissions over time will be lower.

This is a classic example from applied cost/benefit analysis, of needing to be explicit about the relationship between the shout-out price and the overall path that is being followed. It does, of course, create a difficulty for the policymaker: suppose for example that you're assessing the social cost of carbon in the context of a road-building project that will save some travel time and some fuel. What price do you use for the carbon associated with the fuel that is saved? If you think the world is going to be sensible about future emissions, you'll choose a lower price. If you think the world is not going to be so sensible, you'll choose a higher price. It seems to me that if the carbon price really matters to the investment decision that's being taken, you have to look at it very hard and see what kind of probabilities attach to the adoption of different kinds of policies.

I wouldn't place huge emphasis on specific estimates of the social cost of carbon, given that these vary widely. The concept is a valuable one in analysis but much less so as a guide to policy. That's why in my presentation I didn't lay a lot of emphasis on the social cost of carbon as a policy tool, and why we argued that, from the point of view of the economics of risk of the Marty Weitzman kind, one should set stabilization goals and find the path associated with them.

Any given stabilization goal will have a corridor of paths associated with it, and you use your price mechanisms to decarbonize within that corridor of paths, but revise your decisions from time to time as better information comes in. And in that revision, a field for the social cost of carbon would be helpful, but we didn't set that up as the central driving force of the decarbonization policy story as we described it.

CHRIS HOPE:

Nick is very well aware of the political process. I tend to think of the social cost of carbon as what you should use to set any carbon tax that you might have, and I would agree with Nick that you should probably look at what the carbon tax should be under an optimal, rather than under a business-as-usual, path of emissions.

I actually think that you should probably set your carbon tax a little bit higher than the mean social cost of carbon—for various reasons to do with the things that have been missed out of the calculations, but also because the carbon tax is going to be replacing other taxes that distort decision making in the economy.

Even if you accept this point of view, it's still an open research question as to how much the social cost of carbon will change if we move from something like a business-as-usual scenario to something like an optimal path of emissions over time. Maybe the cost will drop by a factor of two or three, or maybe it will not drop much at all. The answer seems to depend quite a lot on your assumptions about what's going to happen to other gases, like sulfates and other background gases in the atmosphere, as you move to your optimal path of emissions.

MEMBER OF THE AUDIENCE:

Was acidification of the oceans included in your calculations of social cost?

CHRIS HOPE:

The PAGE model, as run for this kind of study, doesn't take into account the other impacts that there might be of fossil fuel use. So neither does it explicitly take into account the co-benefits from reducing fossil fuel use, which include the reduction of acid rain.

It is possible to run the model along with other models that track those things explicitly, and find out the total benefit of cutting back, let's say, emissions from fossil fuel. But you have to be quite careful how you do that: if, for example, some of your policy action is to reduce the emissions of CO_2 by reducing deforestation, this won't necessarily yield the same kinds of co-benefits as from reducing the burning of fossil fuels.

NICHOLAS STERN:

I think this is a good example of why you'd want to go for disaggregated descriptions. In our report we did look across a whole range of these kinds of problems, and the decision challenge, then, is: Would you pay one %of GDP to drastically reduce this whole collection of types of risk?

MEMBER OF THE AUDIENCE:

On climate sensitivity, the IPCC process takes models from all the countries in the world that are able to submit data. There is really no quality control—there is no way to check. But if you take the view that those models that simulate current climates well should be considered the more reliable ones for forecasting the future climate, you find out that the climate sensitivity is at the highest range of the IPCC estimates. This is something that the IPCC has decided to investigate further, starting from its next assessment.

NICHOLAS STERN:

I think that's an example of the ways in which we were cautious. We didn't know how to incorporate those kinds of possibilities, though there are some strong signs in the IPCC report. I do think there are lots of uncertainties out there and risks of a major kind that are simply not in the story as we told it.

CHRIS HOPE:

I have done some runs with the higher numbers that seem to be coming through from Murphy and Stainforth and so on. These numbers seem to increase the mean values for the social cost of carbon by at least 50 percent, and possibly a bit more. This is exactly the benefit of this kind of model: when you get better information, you can find out what effect it has on the policy-relevant numbers.

Chapter 4: Closing Remarks

Dean Gustave Speth

First, I must on behalf of everyone here express thanks to Nick and his colleagues for what they've done in this remarkable report, for coming to Yale and spending the day with us, and even more, for putting up with Washington and making the presentations in Washington. We think that was probably the biggest contribution you could possibly make.

This report is the most comprehensive economic analysis that's been done. It will be a point of departure and reference for all future work. I see four main points coming out of it. First, that the risks are very great. Secondly, that the time is very short in at least two senses. One is that the gases are building up rapidly, and we may miss the opportunity to move to that window between 450 and 550 parts per million, and the other is that cost of stabilization is increasing, as the report points out. Thirdly, that action has got to be very significant. The report calls for 60 to 80 % reduction in the rich countries probably by 2050. And, fourthly, that the cost of mitigation can be affordable. You make these points very clearly and persuasively, and we're in your debt for making them. People will argue about many aspects of the report, I'm sure, but I suspect that these four points—these four basic conclusions—will stand up and be very robust.

The good news for all of us here in the United States is that this country has finally come alive with the issue. We seem to have passed through some threshold where it's going to be henceforth impossible for politicians to ignore it, as they have successfully done for the last quarter century.

I can't resist mentioning the fact that it was way back in the Carter administration when we said “the carbon dioxide problem should be taken seriously in new ways. It should become a factor in making energy policy and not simply the subject of scientific investigation.” That was 27 years ago.

I also have to admit that we said this, too: “In particular, we cannot presume that in order to decide whether to proceed with the carbon dioxide experiment we can accurately assess the long-term cost and benefits of unprecedented changes in global climate.” Well, anyhow, here we are. We just did it, didn't we?

But the fact that we wasted a quarter century or more here in getting busy with this problem leads The Stern Review uses the phrase "to avoid the worst," because climate change is now a chronic disease that our planet has, and we will be coping with it for a long, long time. Avoiding the worst is now the best we can do.

The momentum in the U.S. to address the issue started in the states and local governments: California's commitment to 80 % reduction by 2020, New York City is putting in place an aggressive program, and Yale has itself adopted a 43 % reduction goal by 2020.

It's now moved to Washington, and Congress is flooded with cap and trade proposals. And I think we should be excited that at long last this is happening, but we have to temper our euphoria with the knowledge that it will be a hard slog, a hard fight to get where we need to be on this problem, and we haven't got much time.

In conclusion, I have to say, Nick, that I'm one of those who worries that you may have set the stabilization target at a level that could well turn out to be dangerous, too dangerous. I'm afraid, at least based on my reading, which is a layman's reading almost, that this range of 450 parts per million CO_2 equivalent to 550 is an extraordinarily important range. At the low end of that range, we will probably have impacts that we could live with, but at the high end of that range, we're in dangerous territory.

My reading found footnote 23 in the document that you've provided us, based on subsequent work since the report, and it mentions that at 550 CO_2e, there's a 50/50 chance of exceeding warming of three degrees Celsius and that this amount of warming could lead to up to 60 % more people at risk from hunger, with half the increase in Africa and West Asia, to between 20 and 50 % of species facing extinction, and to the risk of abrupt and other major events, such as the onset of irreversible melting of the Greenland ice sheet.

And this is why, of course, the European Union has set a goal of trying to stay below 2°C warming. People like Jim Hansen and many others believe we have to come in below that level to really be safe.

And, so, we're back down at the end of the spectrum closer to 450 ppm CO_2e if we want to avoid the risks of this three-degree plus global average warming. Indeed the report itself mentions that if greenhouse gas levels could be stabilized at today's levels of

430 CO_2e, mean global temperatures would eventually rise to one to three degrees above the preindustrial level. What might we have already done, having raised the gases up to 430 CO_2e?

And the report goes on to say that sensitivity analysis implies that there is up to a one-in-five chance that the world would experience a warming in excess of three degrees Celsius above the pre-industrial levels even if greenhouse gas concentrations were stabilized at today's level of 430 parts per million. In other words, there's a 20 % chance that we've already bought the ranch, as we say.

It does seem to me that this range that you have covered is the critical range between, at the low end, something that we will have to live with and could live with at some level of damage up to something quite unacceptable at the high end.

That's my own comment. You'll have many other comments this afternoon from people who are very expert, and I'm sure that it will be a wonderful discussion. Again, thank you so much for coming and contributing and doing this report and going to Washington.

Part Two: Comments on the Stern Review

Chapter 5: William Nordhaus, Yale University

Opposite Ends of the Globe

The *Stern Review on the Economics of Climate Change* (Cambridge University Press, 2007, hereafter *Review)* has put forth a somber assessment of the risks of climate change. It concludes that “if we don’t act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more.” The *Review* proposes sharp, urgent, and immediate reductions in emissions.

Although using the language and tools of economics, its results are dramatically different from many existing economic models that use similar data and structures. What is the reasoning behind this radical revision? Is it based on sound economic analysis? I will address these questions in my talk. (This talk is drawn from a longer study, *A Review of the Stern Review on the Economics of Global Warming,* forthcoming *The Journal of Economic Literature* and available at http://www.econ.yale.edu/~nordhaus/homepage/SternReviewD2.pdf .)

Areas of Agreement and Disagreement

It will be useful to list the areas of agreement and disagreement, shown on the first slide. Begin with five fundamental assumptions that are widely accepted among natural and social scientists in this area. These propositions are fundamental to the *Review* and to much other research in this area (with many qualifications and reservations).

1. Global warming is state-of-the-art science.
2. Unchecked warming may lead to large and costly long-run ecological and economic impacts.

3. The complexities and uncertainties are enormous in the science, economics, and ecology.
4. Global warming is a major global public good.
5. Solutions will involve raising the market price of carbon

I would pause on the fifth point. Like many economists, the *Review* emphasizes the need for increasing the price of carbon emissions. This might come through a carbon tax or through marketable emissions permits, such as are now traded in the European Union. I will call these "carbon taxes," but this is really a short hand for a market penalty or limitation. A carbon tax is necessary both to provide incentives to individual firms and households and to stimulate research and development on low-carbon technologies. Carbon prices must be raised to transmit the social costs of GHG emissions to the everyday decisions of billions of firms and people. This inconvenient economic truth is virtually absent from most political discussions of climate change policy. In Al Gore's documentary on global warming, he gingerly asked about the costs of slowing climate change. But then he backed away by saying that slowing climate change is an opportunity, not a cost.

The next two areas are ones where the *Review* has staked out quantitative positions that have been more controversial.

6. The trajectories of emissions, temperature, and impacts is very steep, with the potential for a large temperature increase by 2050.
7. The central estimates of climate damages are much higher than many studies while the estimated abatement costs and slightly lower.

What about the description of underlying science, economic trends, costs, and damages? Here, the critics are divided, and some of the other participants have dealt with these issues. The *Review* is a reasonable interpretation of existing science in most areas. It may exaggerate and compound the extreme events, but this may help overcome the usual tendency to underestimate risks and forget about correlated risks. The differences here are probably differences of tens rather than hundreds of percents.

In one respect, the *Review* inflicts cruel and unusual punishment on the English language. In discussing economic impacts, I quoted above the *Review's* finding that "… the cost of climate change [is] the equivalent of a 20% cut in per-capita consumption, now and forever." This frightening statement suggests that the globe is perilously close to driving off a climatic cliff in the next few years. However, when the *Review* says that there are substantial losses "now," this does not mean "today."

In fact, these impacts are far into the future, and the calculations depend critically upon the assumption of low goods and time discounting. Take the extreme-extreme-extreme case of the high-climate scenario with catastrophic and non-market impacts. For this case, the mean losses are less than 1% of world output in 2050 and around 3% in 2100. This becomes 14% "now" because of an extreme assumption about discounting. By annualizing this damage at an infinitesimal growth-corrected real interest rate, this distant rumble turns into the "20% cut in per-capita consumption, now and forever." By my reckoning, this is an exaggeration by a factor of 1000 percent. But the reason is primarily because of discounting, not because of the estimates of damages.

There are two areas of fundamental disagreement, where, in my view, the *Review* lost its way:

8. The role of peer review, modeling, and reproducibility
9. How future economic costs and benefits should be discounted

I will deal with these two issues in my talk.

Review, Reproducibility, and Modeling

The *Review* is a political document and has advocacy as its purpose. But that is London and this is Yale, and I will address it as a scientific study. The central methodology by which science (including economics) operates is peer review and reproducibility. The study does not play by the ground rules of standard science and economics. It was published without a prior appraisal of methods and assumptions by independent outside experts. I could not find a document with sources and methods that would allow me to reproduce the results. I could not retrace their steps.

These may be seen as bowing and scraping to hidebound academic traditions, but it is fundamental to good science and economic analysis, in London as in Yale. These practices help protect authors from correctible mistakes. They help governments from digging themselves ever deeper into their own misguided realities. The British government is not infallible in questions of economic and scientific analysis on global warming, any more than it was on Iraq's weapons of mass production five years ago (*Iraq's Weapons Of Mass Destruction: The Assessment Of The British Government*, September 2002). External review and reproducibility are essential for ensuring logical reasoning and appropriate respect for contrary points of view.

In part, these issues relate to the *Review*'s distrust of models. The Stern team picks and chooses among models. It likes the science models, but it dislikes economic models which have inconvenient findings. It is not apparent whether its policies are internally consistent or consistent with any existing model. Its main modeling effort drew upon the PAGE model, but it changed the parameters so drastically that the mean social cost of carbon was ten times higher in the *Review* runs than in the baseline runs of the modeler himself. It should be emphasized that models are for insights not truth. They are primarily accounting devices for keeping score and ensuring consistency. They help understand this enormously complicated non-linear dynamic system. The message of the *Review* is confused because of its ambivalence to keeping score.

The Discounting Controversy

My second point is that virtually the entire difference between the *Review's* results and those in most other studies lies in its approach to discounting. At the outset, we should recall the warning that Tjalling Koopmans gave in his pathbreaking analysis of discounting in growth theory. He wrote, "[T]he problem of optimal growth is too complicated … for one to feel comfortable in making an *entirely* a priori choice of [the time discount rate] before one knows the implications of alternative choices." This conclusion applies with even greater force in global warming models, which have much greater complexity than the models that Koopmans analyzed. I think the *Review* simply got tangled up in the trees of the high theory of discounting and lost sight of the forest.

The practical implication of the discounting controversy centers on the appropriate real interest rate to use in making investments to slow climate change. (I note in passing that my discussion omits many deep qualifications concerning risk, uncertainty, taxes, borrowing constraints, and the like.) The theoretical apparatus in the *Review* leads to very low real interest rates. The equilibrium real interest rate for the world in their view is 1.4 %per year over the indefinite future.

So when comparing potential investments in climate abatement with those in, say, education in America or China, vaccines in Europe or Africa, or shelter anywhere, the *Review* would discount the costs and benefits from climate investments by this very low rate.

My main concern with the *Review* is that this procedure seriously underestimates the return on investment. Maybe not in Merry England since 1914, but definitely in the United States, China, and much of the rest of the world. Just to provide two important examples: Careful estimates indicate that the real pre-tax return on U.S. corporate capital over the last four decades has averaged about 7 %per year. To go to the wider world, James Heckman finds that there is a vast reservoir of investments in human capital in the developing world. To take China, he writes, “The true rate of return to education in China may be as high as 30% or 40%.” (“China’s human capital investment,” *China Economic Review* 16 (2005), pp. 50–70) I am sure that Jeff Sachs could find a similar large pool of high-yield investments in health and other areas in Africa. Even 20-year inflation-indexed bonds in the U.S., currently yielding 2½ percent, have a substantially higher return than that used by the *Review*.

Economic Modeling With Low Discount Rates

It seems worth a moment to examine alternative discounting assumptions in an integrated economic analysis. Chris Hope provided an example this morning, and I will provide another, and much simpler, example. For this purpose, I draw upon an existing and well-documented model of the economics of climate change, the “DICE model,” which has been updated to the most recently available data, economics, and science. (The most recent runs are available at http://www.econ.yale.edu/~nordhaus/DICEGAMS/DICE2007.htm.) I then make three runs.

Run 1. *Optimal climate change policy in the DICE-2007 model.* This run estimates the path of greenhouse gas abatement that maximizes net economic welfare over the indefinite future. The model assumes time discounting at 1.5 %per year and a utility function that generates market interest rates.

Run 2. *Optimal climate change using the Review zero time discount rate.* This run is the same as Run 1, but it uses the Review's assumption about time discounting and the utility function.

Run 3. *Optimal climate change using a zero time discount rate recalibrated to match market returns to investment.* Like Run 2, this run assumes zero time discounting, but it recalibrates the utility function so that the model generates market interest rates.

What do these calculations show? Figure 1 compares the future path of real returns on capital. The striking point is the different view of capital returns. To implement the low time discounting assumption of the *Review*, the world increases its savings rate sharply, and the real return with the *Review* parameters takes a steep nosedive. The other runs have a slow glide path of returns over time, reflecting the assumed slowdown in the rate of economic growth. I cannot stand here and say that I know that my view is right and that the *Review* view is wrong. But they point to no evidence suggesting that their view of returns on capital is right, and there is substantial evidence that it is wrong.

Figure 2 shows the path of global average optimal carbon taxes in each run. Recall that a carbon tax is a useful measure of the relative tightness of abatement. In the updated DICE model, the calculated optimal carbon tax for 2010 prices is around $30 per ton carbon. The *Review's* ethical parameters have an implicit carbon tax of around $300 per ton carbon. The *Review* does not have a firm recommendation for a carbon price, but they suggest something in the $120 - $140 per ton C range.

If we take the zero time discounting and recalibrate it, the carbon tax looks very much like the DICE run 1. The reason is the balancing of current and future costs and benefits takes place via the real interest rate, and the underlying time discount rate does not directly enter the calculation. The way that the *Review* gets a high carbon tax, a high social cost of carbon, and high emissions reductions is through the low interest rate, not the low time discount rate.

Just to put these numbers in perspective. The global average carbon taxes implicit in the first round of the Kyoto Protocol are approximately one-tenth of the level in the DICE optimal run 1, and approximately one-hundredth in the *Review* targets in run 2. The fiscal transfers from consumers to producers and governments for the United States would be approximately $500 billion for the *Review's* targets in run 2. The carbon restraints, if efficiently imposed, would increase the wholesale price of coal from $25 per ton to $200 per ton. These are indeed ambitious targets!

Summary Verdict

How much and how fast should the globe reduce greenhouse-gas emissions? How should nations balance the costs of the reductions against the damages and dangers of climate change? The *Review* answers these questions clearly and unambiguously: we need urgent, sharp, and immediate reductions in greenhouse-gas emissions.

My conclusion is that economic reasoning does not justify the policy recommendations of the *Review.* The *Review's* radical revision of the economics of climate change does not arise from any new economics, science, or modeling. Rather, it depends decisively on the assumptions of a near-zero time discount rate combined with a particular view on inequality. The *Review's* unambiguous conclusions about the need for extreme immediate action will not survive the substitution of assumptions that are consistent with today's market place real interest rates and savings rates. So the central questions about global-warming policy – how much, how fast, and how costly – remain open.

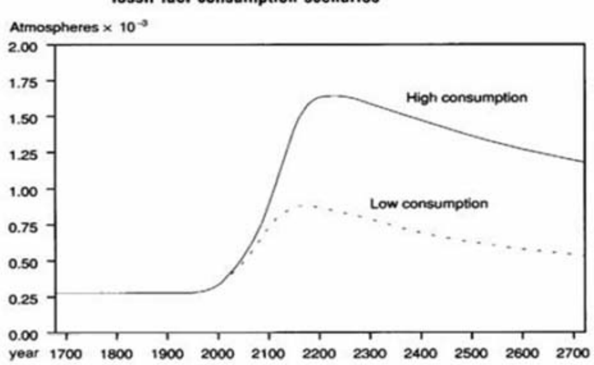
Chapter 6: William Cline, Peterson Institute for International Economics

In my view, this report shifts the state of the debate and moves the burden of proof toward those economists who judge that very little should be done to stop global warming because abatement costs exceed benefits of damage avoided. I think it is high time for such a shift. I will argue that the most important reason the new report comes to the conclusion that aggressive action is highly beneficial in economic terms is that it adopts a near-zero rate of "pure time preference," the rate at which the future is discounted solely because of impatience rather than because of rising incomes. This was the approach I proposed in my 1992 book on *The Economics of Global Warming*, and I am delighted to see that the Stern team has also adopted this view. In broad terms I agree with the Stern Report's findings, although I will suggest some important qualifications.

My Earlier Results

The Stern Review results are similar to those I identified in my 1992 book, even though I used a much simpler model.

Figure 2.2 Atmospheric carbon dioxide concentrations under alternative fossil fuel consumption scenarios



Source: Eric T. Sundquist. 1990. "Long-term Aspects of Future Atmospheric CO_2 and Sea-Level Changes." Reprinted with permission from Roger R. Revelle, et al., *Sea-Level Change*, © 1990 by the National Academy of Sciences. Published by National Academy Press, Washington, DC.

In that analysis I introduced a 300 year time horizon for the analysis, because that is the time it takes for carbon dioxide concentrations to begin falling again from mixing back into the deep ocean, according to oceanographer Eric Sundquist. This meant that I got much higher atmospheric concentrations and far higher eventual warming than the standard 3° C for a doubling of atmospheric carbon dioxide over preindustrial levels. Indeed, my basic estimates of damage avoided by abatement were close to what the Stern Review has obtained: a central estimate of 5 %of GDP by the late 23rd century to a high estimate of nearly 20 percent. I concluded that, with some risk aversion, the benefits of damage avoided would exceed the abatement costs of cutting global emissions from their 1990 rate of about 6 billion tons of carbon equivalent (or about 24 billion tons of carbon dioxide) to a ceiling of 4 billion tons indefinitely. That was a cutback of about 80 %by 2100 from the business as usual baseline. I reached similar conclusions in my more recent paper for the Copenhagen Consensus. The optimal emissions cutbacks from baseline were about 40 %in the first decade, eventually rising to 60 percent. The optimal carbon tax started out at about $150 per ton of carbon, or about 45 cents per gallon of gasoline and $90 per ton of coal, and rose much higher – but in retrospect was probably overstated because of the high abatement costs in the version of Nordhaus' DICE model that I used in that study.

The Discount Rate

By now it seems clear that the central reason for the much more aggressive abatement found desirable in my results, and now the Stern Review results, than in many optimization models is the discount rate chosen to compare costs and benefits over time. The classic statement of the discount rate for such purposes is that by Frank Ramsey in his 1928 growth model.

Social rate of time preference (SRTP)

$$SRTP = \delta + g\eta$$

δ = pure time preference
(impatience)

g = per capita growth

η = (-) elasticity of marginal utility

The social rate of time preference equals the rate of pure time preference, delta in the Stern Review, plus the growth rate of per capita income, g, times the so-called elasticity of marginal utility, eta in the Stern Review. The discount rate on these time scales is crucial. Discounting at 5 percent, for example, $1 million damage 200 years in the future is worth paying only $58 to avoid today. Discounting at 1.5 % one would be willing to pay $51,000.

I agree with the Stern Review that because there is no capital market that extends out one to two centuries, it is necessary to identify the discount parameters from first principles. I set the rate of pure time preference at zero, following Ramsey who called zero pure time preference the only ethical value for comparisons against future generations that cannot take part in decisions today. This is sharply different from the 3% rate of pure time preference that Bill Nordhaus has used, and he and I have agreed to disagree on this issue for nearly two decades now. I set the elasticity of marginal utility at 1.5, a value I derived from the literature but will discuss further. I projected long-term per capita income growth at 1% annually. This meant that the rate of time preference on consumption was 1.5 percent, a rate close to the historic average for the risk-free rate on treasury bills, which is the rate at which households can safely transfer consumption across time. I also applied a shadow price of capital to all investment in future output, to capture the difference between the rate of return on capital and the social rate of time preference – the approach of the social cost benefit literature pioneered by Arrow, Bradford, and Feldstein. After taking account of shadow pricing of investment effects, the overall effective discount rate was in the range of 1.5 to 2%.

Although the Stern Review uses a lower value for eta, it has a higher average growth rate, 1.3 percent, whereas I used 1 percent. The end result is that at 1.4% annually (or somewhat higher in initial years when growth is higher), the Review's discount rate is about the same as mine, although the Stern Review does not shadow price capital so its overall effective discount rate is somewhat further below mine.

The central difference in my results and now those in the Stern Review in contrast to many Integrated Assessment Models of global warming is the adoption of a zero or near zero value for pure time preference, or impatience (delta). The Stern Review sets delta at 0.1%, almost zero but with a small allowance for humanity's self-implosion. Without this 0.1%, the Review's use of an infinite time horizon simply explodes. The time horizon is the first place I would like to register a qualifier to the Review's results.

Welfare Equations – Stern Report

$$W = \sum_{t=1}^{2200} N(t)\ln C(t)e^{-\delta t} + \left(\frac{N_T \ln C_T}{\delta} + \frac{N_T g}{\delta^2}\right)e^{-\delta T}$$

$$W = \sum_{t=1}^{2200} N(t)\left(\frac{C_{BGE}^{1-\eta}}{1-\eta} + gt\right)e^{-\delta t} + \left(\frac{N(t)\left(\frac{(C_{BGE}+200g)^{1-\eta}}{1-\eta}\right)}{\delta - g(1-\eta)}\right)e^{-\delta T}$$

This equation shows the calculation of the present discounted value of the future welfare in the Review. Consider the top panel, which shows welfare when the elasticity of marginal utility equals unity and utility rises with the logarithm of consumption. The first term is the discounted value of future welfare from now to 200 years from now. The second term is the value of all welfare thereafter. If you put this equation on a spreadsheet, you will find that 93% of all future welfare occurs after the year 2200. That explains the biggest paradox in the Stern Review. It states first that damage rises gradually and only reaches the 5 to 20% of GDP range by 2200. But then it says that the damages are equivalent to 5 to 20% of GDP "now and forever." What is really happening is that the first century disappears into insignificance and the "now and forever" is almost entirely what happens after 2200.

In contrast, I based my analysis on a 300 year horizon, because after that concentrations could begin to fall once again and there should be a partial decline in the cumulative warming. So the first qualification of the Stern Review is that it probably should not have extrapolated the damage rate of 2200 into the infinite future, because that probably overstates the future baseline damages. Even if there are irreversibilities that could leave some damages high despite an eventual partial decline in temperatures – such as melting of the Greenland ice sheet – the relative weight of distant future damages may be overstated. Moreover, at the most fundamental level, it becomes increasingly fanciful to think about effects on the scale of say 3000 years from now, which is still a long way from infinity! Discounting at only 0.1 % pure time preference, $1 million at 3000 years from today is still worth $50,000 today.

It is the combination of a near zero rate of pure time preference with an elasticity of marginal utility of unity, however, that generates truly explosive welfare effects with an infinite horizon. Consider the bottom panel of the figure. This panel shows the Balanced Growth Equivalent level of consumption, C_{BGE}, that generates the same total present value of welfare as the top panel equation. Once again the contribution of the first two hundred years is the first term, and the contribution of everything after that out to infinity is the second term. If you look at the denominator of the second term, you will see the term delta, or pure time preference, which is close to zero; and the growth rate "g" multiplied by one minus the elasticity of marginal utility, eta. In effect the second term is capitalizing the post-2200 future by dividing by the effective overall discount rate, which subtracts off the utility effect of the growth rate in the denominater as the way of taking account of an ever-rising level of consumption. As eta approximates unity, the denominator of the second term approaches nothing but delta, which in turn is close to zero, and division by zero causes the value to explode toward infinity. However, if eta is on the order of 1.3 to 1.5, this denominator in the second term soars from 0.1% to the range of 0.4 to 0.6%, cutting the capitalized contribution of post-2200 welfare to one-fourth to one-sixth the previous amount. As a result, using an elasticity of marginal utility in the range of 1.3 to 1.5 will greatly reduce the extent to which the future benefit of damage avoided may be exaggerated by using an infinite horizon.

In short, the combination of near-zero pure time preference with an infinite horizon probably balloons the value of damage avoided unreasonably. Instead of the benefits being 5 to 20 % of GDP now and forever and the costs of abatement being only 1% of GDP, the benefits could be considerably smaller if the horizon is limited to three centuries or even five to ten centuries. Of course, with such a large gap between the benefit of damage avoided and the estimated costs of abatement, the Stern Review has considerable cushion for reducing the damage estimates and still finding a favorable benefit-cost ratio for aggressive action.

I would argue that if the time horizon is to be extended to infinity, there should not only be more explicit attention to lower damages after 2300 because of partial reversal of global warming, but also that it is important to apply a somewhat higher elasticity of marginal utility than the value of unity used in the Review. All this being said, I would note that with the recent work by Meinshausen and others suggesting that even 2.5°C global warming would be likely to cause dissolution of the Greenland ice sheet and sea level rise of 7 meters on a time scale of 1,000 years, and in view of recent concerns that this melting could occur faster than previously thought, it may indeed make sense to extend the horizon to at least a few hundred years beyond my 300 year horizon – as long as this is done with a somewhat higher elasticity of marginal utility than used in the Stern Review in combination with the near zero rate of pure time preference.

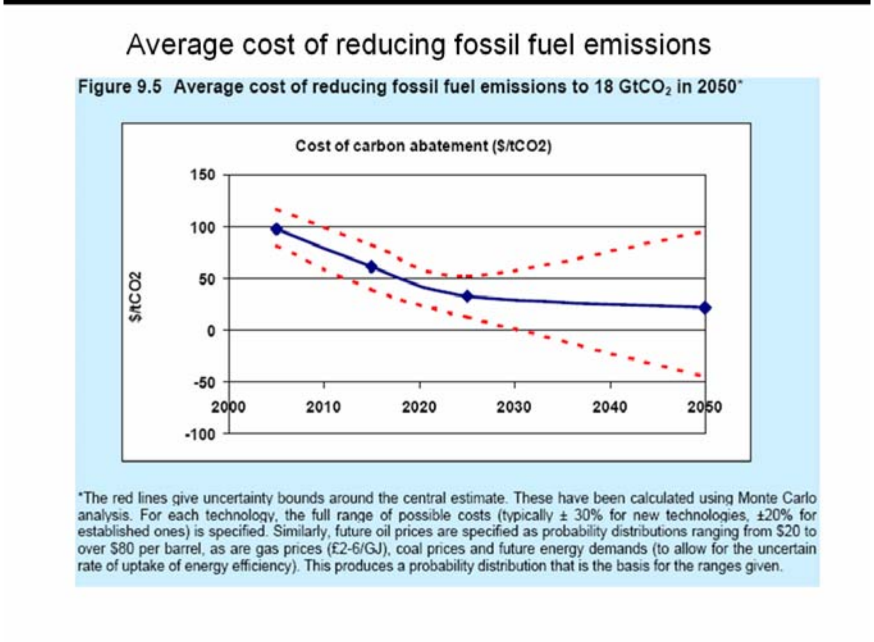
How Rapidly Does Marginal Utility Drop Off?

It would be a mistake, however, to go to the opposite extreme and increase eta to the range of 3 to 4, as suggested by Partha Das Gupta. The value of 1.5 that I use is based in part on the econometric literature in finance, which measures this parameter as what is called the constant rate of relative risk aversion. Whereas Das Gupta agrees with Stern and with me that pure time preference should be set at delta equals zero, he argues that unity is too regressive a value for the elasticity of marginal utility, eta; and by implication the value of 1.5 that I use is also too low. If you think about it, the value of unity used by Stern is the same value that is in the bible for this parameter. The biblical tithe means that society's loss in private utility when a rich man gives up 10 %of his large income is just the same as the loss in private utility when a poor man gives up 10 %of his income. That is exactly what a value of eta = 1 means, and today we would call this a flat tax, and would call it regressive. Progressive tax systems set tax rates higher for the rich, implying that society presently thinks that marginal utility drops off somewhat faster than implied by the biblical tithe. Das Gupta thinks the progressivity should set eta at 3 or 4 instead of unity.

To examine his argument, I have done a back of the envelope calculation to see what our present tax structure implies about the elasticity of marginal utility. As a stylized fact, suppose a family earning $23,000 pays 15 %tax (payroll, employer and employee), while a family earning $667,000 pays a tax of 40 percent. It turns out that the parameter value for eta that makes the social welfare burden of tax payment equal for the two families is 1.35 – slightly smaller than the value 1.5 that I used. If instead the parameter were set as high as 3, then the tax that would have to be levied on the family earning $667,000 would be an average tax rate of 95 percent. Even at eta =2 the average tax rate for the rich family would have to be 84 percent, to make the social welfare burden of tax identical for the rich and poor family. So I would submit that the value of eta of 1.5 that I used is much closer to how society behaves than the range of 3 to 4 suggested by das Gupta.

When to Act?

The Stern Review seems to argue that there should be an immediate move to a carbon tax of $85 per ton of carbon dioxide, or $312 per ton of carbon.



It then sees the carbon tax falling to half by 2018 and stabilizing at a plateau of about $120 per ton of carbon by 2025. This profile is the opposite of most optimal carbon tax paths, which tend to start lower and then increase. The result is driven by the imperative of keeping atmospheric concentrations below about 500 parts per million, and the eventual decline reflects improving technological opportunities. The initial tax is about twice the initial optimal tax I estimated in my Copenhagen Consensus paper, though the eventual tax is far lower because of more optimistic abatement cost estimates with future technological breakthroughs. My sense is that the political economy of making clear a strong commitment so the private sector takes the carbon price seriously requires at minimum a carbon tax of some $50 per ton of carbon in the near term, and a clear indication that the tax is headed to well over $100 per ton within a decade. It seems quite possible that such a path could largely accomplish what the Stern Review seeks without being so disruptive up front that the effort fails in the face of strong resistance.

Conclusion

My most basic evaluation of the Review, however, is that it is very much on the right track. It is high time that the center of gravity in economic analyses of global warming shift toward recognition that with appropriate discount rates the benefits of aggressive action warrant the costs of abatement. Increasingly, moreover, economists seem likely to move toward recognizing the dangers of uncertainties in the so-called "fat tails" of the probability distributions of damages, as emphasized by Martin Weitzman in his seminar here at Yale earlier this week, and correspondingly begin to endorse aggressive action as a reasonably priced insurance policy against potential disasters. The insurance policy approach complements what I think is already a correct, if arguably overstated, positive benefit-cost profile for aggressive abatement as identified in the Stern Review.

Chapter 7: Gary Yohe, Wesleyan University

The *Review*, of course, has turned into a little bit of a "full employment act" for economists who know a little bit about climate. We are likely to be busy for quite a while in the wake of its release, and so it is good to pause for a day to take stock of what we know and what we need to do, now.

I've been asked to think a little bit about the stabilization side of the *Review*. As I do, I want to start by identifying Richard Tol as a collaborator and co-author in much of what I've put together over the past three months in response to the *Review* [see Tol (2006), Tol and Yohe (2007), Yohe (2006), Yohe and Tol (2007) for a chronicle of our thinking]. Richard and I have both learned an enormous amount as we have tried to work through its details.

In turning to consider the mitigation side, it is still important that we continue to recognize the most recent science as presented by the *Review,* but I think that it is important to apply that science to best serving decision-makers who face the question of what to do over the near term. In that regard, it seems to me important to them out from the burden of solving the climate problem. That is simply not going to happen. We are not going to set policy in 2007 for the entire century. Today's decision-makers must acknowledge the problem, to be sure, but they should try to design policy for the near term that minimizes expected adjustment costs as the science evolves while they work to create a long-lasting institutional structure within which that science can be taken on board without political manipulation.

To reiterate some of the important natural science points raised in the *Review,* the recent literature suggests that climate change is changing more rapidly than we thought five years ago. It also concludes that impacts are likely to become more severe as time goes on and temperatures rise. Some impacts have already been observed and attributed to human activity; and others are likely to be felt sooner than thought only five years ago. Rachel Warren and colleagues (Warren, et al., 2006) crafted a wonderful supporting document to emphasize these points. Their assessment of the science is, in fact, entirely consistent with contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) that was approved in Paris two weeks ago at the end of the most recent plenary meeting of the Conference of the Parties of the United Nations Framework Convention on Climate Change.

Figure 1 replicates the summary figure of impacts from Chapter 3 of the *Review*. The major conclusions are displayed in its lower panel, but it strikes me that the most important conclusion is portrayed in its upper panel: no temperature target can be guarantied by any feasible concentration limit. The best that we can do is to characterize the range of uncertainty (expressed in terms of increases in global mean temperature) that could be achieved by any specific concentration stabilization target. We can then look to the lower panel to see what climate risks might still exist, but we cannot assume a one-to-one association between temperature and concentration. This conclusion makes it clear that the question of choosing near-term climate policy is best approached as a risk-management problem and not the result of a tractable cost-benefit calculation.

Many authors have argued with the cost estimates presented in the *Stern Review,* just as many have criticized its benefit estimates. It seems to me, however, that focusing on either set of numbers runs the risk of missing the point if the question is how best to inform decisions about near term mitigation. How, more specifically, can we design near-term policy that would be consistent with the long-term objectives that will, of necessity, change as our understanding of the science evolves? And as the science evolves, how should we allocate our scarce time and research efforts to sort through persistent uncertainties and confounding controversies most efficiently? For a good friend of mine, Lester Lave, from Carnegie Mellon, the answer to the second question is two – i.e., if resolving the uncertainty about a specific factor doesn't make a difference of a factor of two in a variable of interest (like temperature change or the likelihood of an abrupt impact), then it is “inside the noise” and you should probably move on and look for something else to worry about.

I will apply Lester’s criterion in a minute, but first I want to spend a minute or two on the risk-based per capita consumption metric that the *Review* employees in making its damage estimates. It is provocative and innovative application of sound fundamental economic theory; and it can help. From what I understand, the *Stern Review’s* author team computed multiple per capita consumption runs using Chris Hope's PAGE2002 model [see Hope (2006) for documentation]. They then computed the discounted utility for each one of those runs at 0.1 % discount rate. Then they computed expected discounted utility across the full set of runs given the probability weights from the PAGE2002 model. And finally they computed a certainty equivalent level of consumption, which, if it were to grow at 1.3 % per year starting in 2007, would generate a level of discounted utility equal to the expected utility across all of the underlying runs. They captured, in other words, all that complication and all that future into one number; and the damages attributed to climate change were simply the difference between in those numbers with and without climate change.

This process produces results that express the expected damage associated with unabated climate change across a wide variety of futures as the equivalent of a 5.3% reduction in per capita consumption "now and forever". This does not mean that we will wake up tomorrow and notice that we have lost 5.3 % of our per capita consumption. It means that the discounted values of damages driven by 200 years of climate change *and* the risk premiums associated with the current state of knowledge (i.e., current range of uncertainty in critical parameters) sum to a number that is the equivalent of that reduction. The quoted damages estimates are nothing more than a cardinal metric of utility loss calibrated in terms of per capita consumption.

As I suggested before, some have argued with the *Review's* estimates of mitigation costs; most claiming that they are significant underestimates at best. Mitigation costs depend, of course, on policy design (flexibility, persistence, and predictability) and what the government might do with any revenue that it might collect. That said, I am personally a little puzzled about why the *Review* focused on the 550 ppm concentration target that had been justified by earlier studies released in the United Kingdom on the basis of much smaller damage estimates. If damages are now so much larger, why not discuss a lower target?

Would changing the concentration target satisfy Lester Lave's factor of two rule? That is hard to say. The reason for going through the description of the certainty equivalence applied in damage calculation was to show why it is so difficult to compare damages (and thus the benefit side of the policy equation) with mitigation costs that the *Review* expressed in terms of the percent of GDP lost through 2050. Indeed, readers are never able to really see in the review comparison of those numbers. They are never able to judge the results of a proper cost-benefit comparison, as a result; and they are never told how much the cost of mitigation might decline if the metric included the value of reduced risk implied by various mitigation targets (i.e., reduced variation across discounted consumption streams generated by the more certain futures of restrained emissions).

Richard and I responded to this omission by conducting our own comparison using *Stern's* consumption equivalent metric. To do so, we constructed a very, very simple climate model with three regions. We imbedded a few assumptions about climate sensitivity, rates of economic growth across regions, different calibrations of vulnerability to climate impacts, and so on. We calibrated the model so that unabated climate change would achieve maximum concentrations at about 1000 ppm and support a damage estimate equal to losing 5.3% in per capita consumption equivalence. Table 1 shows the results for various concentration targets. A reduction in damages from 5.3 % down to 2.2 % was achieved by a 550 ppm limit; and a 400 ppm target lower damages below 1%. Clearly, changing the concentration target of climate policy satisfies Lester's rule. To be clear, though, these estimates of benefits (damages avoided) do not indicate the net value of mitigation, because the cost of mitigation is not included in the calculation.

Are there any other simple factors that sort of would satisfy Lester's rule? The discount rate has, of course, attracted a lot of attention. In our little model, lowering the discount rate from 0.1 % to 0.01 % caused damages to increase only slightly from 5.3 % to 5.4%. It follows that the 0.1 % rate chosen by *Review* authors is a pretty good approximation of zero; pushing further in that direction doesn't do much and Lester would warn against spending much time doing so. Raising the rate to 1.5 % would, however, reduce damages by more than 50%; in this regard, we simply confirm something that was to be expected.

We also wondered what would happen to damage estimates if vulnerability were not assumed to be a static percentage of GDP. What if vulnerability fell with income in poor countries? We calibrated this reduction so that vulnerability there would match current vulnerability in the developed world if and when per capita consumption reached current levels in the developed world. The result was another 50 % reduction in aggregate damages.

Notwithstanding these issues, I think that the *Review* does provide enough information to support an economic case for immediate action. The *Review* portrays climate risks, as currently perceived, quite clearly. Any reader identify a risk that he or she would call “dangerous”, translate that into a temperature target of “tolerable climate change”, and then examine the effects of achieving various mitigation targets (expressed in terms of greenhouse gas concentrations) on the likelihood of crossing his or her critical threshold. This is why Figure 1 is my favorite picture in the whole *Review*. The red arrows highlight a list of possible events that could be considered “dangerous” by one reader or another. It identifies temperature triggers for each event. And it shows what happens to the likelihood of crossing that threshold if concentrations were limited to 550 ppm, or 450 ppm, or 650 ppm.

A reader who agrees with the European Union that two degrees is a good target would, for example, see that that a 550 ppm concentration limit would still leave a 70 or 80 % chance of exceeding the temperature threshold. A 400 ppm limit would leave a 30% chance, and so on. A reader who was less concerned with impacts that could begin with another 2 to 3 degrees of warming might pick a 3 degree target. A 550 ppm concentration limit would make it a coin toss that this reader would be disappointed; and a 400 ppm would make it a role of a dice.

Once this mental exercise has been completed, then the simple economics of the Hotelling rule applies. To a first approximation, any concentration target is a cumulative emissions constraint. As a result, the long-term climate policy problem becomes an exhaustible resource problem for which the solution is well known: pick an initial scarcity rent and let it grow at the rate of interest.

What about the short-term policy problem? Debate over what to do now must acknowledge climate risk in the context of its inherent long time horizon, but it must also think about the political tractability. A carbon price of $30 per ton of CO_2 (or $100 per ton of carbon) seems to be a magic number for which electric power plants might switch from coal to natural gas and where a number where carbon sequestration might become economic. But the price of carbon does not have to be at $100 per ton in 2007 to be effective. If it is going to increase at the rate of interest in a predictable and persistent way, then the initial price (scarcity rent) must be set at a level for which the present value calculations of the private sector investors (using private sector discount rates that are not vulnerable to all of the controversy about how to discount the distant future) favor less carbon-intensive processes.

A $50 per ton price on carbon ($15 per ton of CO_2 or twice the level currently incorporated in draft legislation before the Senate Energy Committee) would, for example, reach $100 around 2021 with a 5% interest rate. Investors are smart. They would see that coming. They would factor that into their calculations; and the near-term policy would not have to be draconian. The fundamental notion is to try to figure out ways to avoid enormous locked-in investments that would commit the economies of the world to high-carbon-intensity means of production and transportation for decades to come. The opportunity to make money by being a first mover in response to a predictable policy environment should be the goal.

There are at least two critical points to be made about adaptation in a discussion of mitigation. First of all, adaptation to climate *will be required* regardless of what we do in the near term. Even if we shut down emissions of all greenhouse gases tomorrow, we are already committed to almost another half a degree of warming over the next 50 to 100 years. Secondly, human systems will adapt to climate change *and to climate policy* as the future unfolds. Some have argued that we have overestimated damages because we have underestimated the ability of communities and systems to adapt. That may or may not be true, but parallel reasoning suggests that we may have also overestimated the cost of mitigation because we have underestimated the ability of systems to adapt to the policy.

In closing, I want to thank Sir Nicholas and his team for having the courage to take on this enormous challenge and for coming here and continuing the debate and for teaching me so much about all of this. I also want to thank Yale for allowing me to return to New Haven to participate in the continuation of the community's review of their work.

Chapter 8: Robert Mendelsohn, Yale University

I recognize that as an official document of the British government, the Report and the process of writing the Report was under political constraints. Writing the Report was made only the more difficult by the fact that the Report was due in such a short time. This Yale critical review of the Report is in fact the first public peer review of the Report and as such is quite important. Unfortunately, it is too late to amend the Report. I understand that there is not to be a Stern Review II. However, this critical review is nonetheless useful to place the Report in context with respect to both the existing literature and existing policy.

My personal belief is that the Stern Review makes a serious effort in the right direction, but it is not a finished analysis. I was hoping that there would be a Stern Review II that would complete many of the analyses which are partially completed in this Report.

When I listened to Sir Nicholas this morning and when I read the Report, my initial impression is that there has been a tremendous analysis that has led conclusively to an unquestionable finding that society must initiate a crash program to control greenhouse gases. Not only do we need controls, but we need severe controls on greenhouse gas emissions that involve immense near term expenditures on carbon mitigation. It was a very awe inspiring presentation complete with thunder and lightening.

Unfortunately, my job today is to take the role of Toto in the Wizard of Oz. Just how powerful is this wizard and what is his command of the truth? Is the Stern Review a complete revision of the economics of climate change or is it merely smoke and mirrors? Is the Review substantive and authoritative or is it mostly hand waving? As my role indicates, I think the Report largely is the latter.

If the Report were substantive, it would show that the preferred policy (stabilizing greenhouse gas concentrations at 550ppm) minimizes the sum of mitigation costs and climate damages. That is, of all the possible strategies to control greenhouse gases, this strategy is the least cost alternative for society. The report would show that its preferred policy balances marginal abatement cost against the present value of marginal damages.

All alternative policies would be shown to be inferior. The Stern Review never makes this analysis.

The Stern Review begins with the conclusion that stabilizing greenhouse gas concentrations at 550 ppm is best and then merely compares the mitigation cost of this policy against doing nothing at all for 200 years. This comparison is not an economic analysis nor is it a reasonable policy analysis. Comparing the cost of a single policy against doing nothing at all does not prove that the policy is the best alternative.

Imagine if we were talking about education policy and I argued "I have a great policy for educating children and look it is better than closing all schools." Presumably, you would not be convinced this is necessarily the best educational policy. You would want my policy compared against other possible ways to educate children. Similarly, I could argue "I have a great health policy and look it is better than having no doctors, nurses, or medicine". Again, you should not be impressed. You should demand that my preferred policy be compared against other plausible health policies that could be implemented.

To prove a policy is optimal, it must be compared against other possible policies. The Stern Review does not do this. It does not examine the efficacy of stabilizing concentrations at 550 ppm versus 650ppm or 750ppm. The Stern Review is not an economic analysis. It may present mitigation costs and impacts measured in dollars, but it is not an economic analysis. The Stern Review does not present an economic analysis showing that that stabilizing concentrations at 550 ppm is best. The Stern Review merely asserts that this is the best policy.

One of the difficulties of writing a Report of this magnitude in such a short time is that it is difficult to keep the entire effort integrated. The Report reads as if there was a team of experts that studied the mitigation costs of stabilizing concentrations at 550 ppm and another team of experts that just studied the impacts of doing no abatement at all. The two teams were never integrated. They did not make the same assumptions about the discount rate, GDP growth, population growth, and energy growth. The Report did not use a single integrated model to look at both abatement costs and benefits.

One of the beauties of having an integrated model is that it forces you to make consistent assumptions. It is very difficult to manage a project of this magnitude without having a central model that combines the results of all the relevant experts. Further, with an integrated economic model of climate change, it would have been easy for them to have conducted the economic analysis that was supposed to be the heart of this effort.

The Stern Review places little weight on the conclusions reached by earlier studies of climate change. The economic literature tends to favor slowing not stopping climate change in the near term (Nordhaus 1991; Nordhaus 1994; Manne et al. 1995; Plambeck et al. 1997; Nordhaus and Boyer 2000). These preferred policies stabilize concentrations at much higher levels than 550 ppm. Stabilization targets of 650ppm, 750ppm, or higher are consistent with most of the economics literature. The reason the higher targets are preferred is two fold. First, carbon mitigation is expensive. In order to reach a 550 ppm target, society will have to begin aggressive near term mitigation that will cost hundreds of billions of dollars in the next few decades. With a 650 or 750 ppm target, near term mitigation can be modest, postponing substantial mitigation costs until the second half of the century. This dramatically reduces the present value of the cost of mitigation. The second reason that economic studies argue that stabilization targets should be lower is that the impacts of climate change are not very large until much higher concentrations are reached. So the cost of mitigation to hold concentrations at 550 ppm rather than 650 ppm are much larger than the additional climate damages associated with going from 550 ppm to 650 ppm. The economic analyses suggest that a 650ppm alternative or higher is a better choice for society than the 550ppm alternative.

The Stern Review does not directly refute the results from the economic literature because the Review does not show any analysis. However, the Stern Review does suggest that there may be assumptions in the earlier analyses that have led them to underestimate the impacts of climate change and overestimate the costs of mitigation. The Stern Review argues that the literature has made numerous errors by failing to make the correct assumptions for climate change. The Report argues that if the literature only made the assumptions in the Report, the literature would reach the same conclusions. Looked at from a different perspective, the Stern Report provides a list of the assumptions that are necessary to argue that aggressive near term mitigation is efficient. If these assumptions cannot be justified, then the conclusions of the Report are invalid as well.

Probably the most controversial and important assumption made by the Stern Review is that the discount rate should be 1.4%. This, of course, is the focus of several other commentaries on the Stern Review so that I will cover this assumption only briefly (Nordhaus 2007, Dasgupta 2007). By choosing such a low discount rate, far future impacts matter today. The Stern Review can therefore look far into the future (for example by 2200) and argue that future impacts bear some consequence to what we ought to be doing about climate change this decade. At a 1.4% discount rate, $1650 of damage in 2200 has a present value of $100. However, at a 4% discount rate, $1650 of damage in 2200 has a present value of only $0.55.

The Stern Review argues that choosing this very low discount rate is morally correct because it effectively does not discount the future. They argue it is the only fair approach to future generations. However, by choosing a very low discount rate, each generation must save a vast fraction of their income for capital for future generations. The Stern Review argues we owe this to future generations. However, a low discount rate makes every generation indebted to future generations. In pursuit of equity, every generation is made worse off. Clearly this is not a morally superior outcome.

Further, if the impact analysis assumes that the discount rate is 1.4%, then the mitigation cost analysis must also make that same assumption. However, investment dollars devoted to the market economy still earn the market rate of interest. Consequently, every $1 of investment taken from the economy and spent on climate change has an opportunity cost equal to the market rate of interest discounted at 1.4%. That is, the opportunity cost of a dollar invested in climate mitigation is .04/.014 or $2.9. The mitigation costs sited by Stern need to be increased by a factor of 2.9 in order to take into account the low discount rate assumed in the damage analysis.

Another important assumption made by the Stern Review is that the damages from climate change would have an expected value of 5% of GDP. The current literature suggests that the damages from a climate warming of about 5˚C are close to 3% of current world GDP or about $600 billion/year (Mendelsohn and Williams2004; 2007; Tol 2002a; 2002b). However, the Stern Review makes the mistake of assuming that market damages would be close to 5% of the world's future GDP or about $60 trillion/year. Although one can make any assumption one pleases, there is no empirical evidence that supports the Stern assumption. The impacts that are anticipated in all the climate sensitive market sectors add up to 1/100th of this amount. The Stern Review overestimates market damages by two orders of magnitude.

The Stern Review also assumes that nonmarket damages will be equal to 5% of future GDP. It is quire clear that there will be nonmarket damages associated with climate change. Tundra will shrink and therefore polar bear habitat will shrink as well. Infectious diseases will spread from their current domain and so there will be additional pressure to extend appropriate public health responses. Some secondary air pollutants will form at a faster rate forcing additional abatement. Ecosystems will shift poleward forcing conservationists and homeowners to change how they manage land across the planet. However, there is no evidence that these changes amount to more than the $600 billion/year damages associated with market impacts. There is no empirical support for the assumption in the Stern Review that nonmarket damages will be $60 trillion/year. Again, it is likely that the Stern Review has overestimated damages by two orders of magnitude.

A third assumption the Stern Review makes in the impact analysis is that extreme events, such as hurricanes and tornadoes, caused by climate change will cause $60 trillion dollars of damage per year by 2200. The current level of damages caused by storms is about $140 billion/year. In order for the damages from storms to reach $60 trillion/year, the damages of storms due to climate change alone would have to increase by over 400 times. Scientists have just been able to show that climate change has a detectable effect on storms in North America (International Panel Climate Change 2007). This is a long way from indicating that damages will increase by 400 times. Again, it is likely that the Stern Review has overestimated damaged by two orders of magnitude.

The Stern Review also wants to inflate damages because they are largely born by poor people from the low latitudes. It has long been suspected that low latitude countries are more vulnerable to climate change than mid to high latitude countries (Pearce 1996). However, more recent research indicates that low latitude countries may well bear the brunt of climate change absorbing most of the damages (Mendelsohn et al. 2006). The Stern Review is correct in raising this inequity to the public's attention. However, if the problem is equity, the solution is not to spend more money on abatement. If one is concerned about the impacts on poor people, the appropriate policy is to engage in direct compensation. Poor countries should be given assistance to help with adaptation and to help with development. Adaptation funds can reduce the damages that each country must endure. Development funds can help countries move away from climate sensitive economic sectors such as agriculture and into economic sectors that will not be affected by climate change. Using funds that could be used for compensation to fund mitigation instead not only earns a low return but it makes poor victims worse off.

In addition to making very strong assumptions to overestimate damages, the Stern Review also makes a number of assumptions that likely underestimate abatement costs. The Review assumes that the mitigation program will be global and efficient. This is a likely outcome if the program starts slowly and learns from its mistakes. However, crash programs that start abruptly with mandates to move forward at all costs are rarely efficient. The idea that an expensive program of mitigation could be organized by 2050 across the entire world is ambitious indeed.

The Stern Review argues that their 550ppm stabilization policy requires that carbon emissions be reduced by 60% by 2050. If such a program were instituted with today's technology, the average abatement cost would be $400/ton of carbon (Anderson 2006). Multiplying this average cost by the 40 billion tons removed yields a total cost of abatement of $1.6 trillion/year. However, the Stern Review argues that technical change will reduce abatement costs by 3% a year. Consequently, they argue that the program would only cost $357 billion a year by 2050. The cost would be less than $100 per ton. Sir Nicholas argues that such high rates of technical change make sense because carbon mitigation is a new field. It is easy to point to many successful technologies that have achieved rapid rates of cost reductions. However, it should also be remembered that there are many technologies that proved to be very expensive in the long run and have since disappeared. The Stern Review is probably correct that future mitigation technologies will be cheaper than what is available today. It is yet another argument why it makes sense not to spend too many abatement dollars too soon. However, it is debatable that technical change will proceed as rapidly as the Review predicts.

The Review argues that it can reduce the emissions from land use by halting deforestation. It estimates that the cost of reducing deforestation is quite low because it is cheap to protect remaining standing forests. There are two problems with this argument. First, most of the world's forests that are economical to harvest have already been cut, so that there are not large gains to be earned from "better" conservation programs. Second, it is hard to prevent local people from cutting forests that are profitable to harvest. Stopping local harvesting requires a local police force that is not in the interest of local and often national interests. The cost to the international community to stop this harvesting may be higher than the Review anticipates.

However, the critical carbon emissions to stop concern the energy sector. The Review places great hope that a method will be found that can take the carbon out of smokestacks so that the remaining fossil fuels can still be burned. Currently, such technology is known but it is not clear how expensive it will be. More importantly, it is not clear where to put the stripped carbon dioxide on it is removed from the smokestack. One plan is to place it in the deep oceans. However, scientists are concerned such plans may cause biological damage in the deep oceans and the carbon dioxide may eventually circulate back to the surface. It has also been suggested that the carbon dioxide can be pumped into natural gas wells. Carbon dioxide infusion is currently used as a method of pressuring natural gas out of these wells. However, it is not clear how quickly the carbon dioxide will escape these storage areas or how much storage volume is conveniently located near emission sites. If a solution to this storage problem is not found, the whole idea of stripping carbon must be abandoned.

The Review fails to take into account the effect that a strong abatement policy will have on the value of fossil fuels. The Review assumes that the value of fossil fuels will remain unaffected by their carbon policies. However, the stabilization plan advocated by the Review is very likely to depress the value of fossil fuels, especially coal. In fact, if the abatement program cannot find an effective way to strip carbon from smokestacks, it is very likely that coal simply cannot be used at all. It will have to be left in the ground. This lost value is not currently measured in the Review.

The remaining alternative to reducing carbon is to find renewable energy sources. Although there are many renewable energy sources, the scale of renewable energy required is daunting. For example, one plan mentioned in the Review suggests a combination of two million windmills, a doubling of nuclear power plants, 10 million hectares of solar cells, and 500 million hectares of biofuel. The plan assumes that the scale of these activities will only lower the cost. However, it will be difficult to site this many facilities which may increase the costs substantially. Further, the price of arable land will certainly increase if such a vast fraction of land is suddenly devoted to energy crops. In fact, taking away 500 million hectares of cropland for renewable energy is very likely to have a much larger impact on agriculture than climate change.

Finally, the Stern Review ignores the environmental damages associated with its renewable energy program. It is very likely that citizens will find doubling nuclear power plants to be a very dangerous idea. It is not apparent whether the risks of nuclear energy are smaller or larger than global warming. Citizens are also likely to balk at any increases in dams for hydropower. Most attempts by developing countries to harness their own hydropower have met with stiff resistance from the international environmental community (e.g. Three Gorges Dam). Perhaps the most dangerous plan of all is to store carbon in temporary quarters. If this carbon is later released it will result in the catastrophic climate outcomes that the mitigation effort was intended to prevent.

Examining this long list of assumptions, it is clear why past economic studies have not reached the same conclusion as the Stern Review. In fact, one can look at the Stern Review as a fairly complete argument why aggressive near term abatement does not make sense. The assumptions required to argue for aggressive near term abatement are long and unlikely. The prudent path is to begin with a modest abatement program that turns global as quickly as possible. The program should at first focus on being efficient and global in coverage. As time progresses, the targets of the program should be gradually tightened so that there is significant abatement planned for the second half of this century. This will give countries plenty of time to negotiate a world treaty. This will give companies and citizens plenty of time to prepare for future abatement. This will delay abatement expenditures into the next half century when costs should be much lower. Yet, this plan would protect the planet from dangerous levels of carbon dioxide accumulating in the atmosphere.

In the end, however, we must thank Sir Nicholas for his contribution and move forward. It is up to all of us to take the next steps. We must all share this burden of analyzing climate change and determining optimal policies.

What research needs to go on? I believe that we've spent a tremendous amount on natural science linking greenhouse gases and climate change. We have spent very little money, however, on either the costs of mitigation or the link between climate changes and damages. We need to better understand both of these issues if we are to make sensible policy in the future.

Of course, we have spent considerable resources understanding impacts in the United States. However, when you start looking around the world, we know much less. We need to study what is going to happen around the world. In fact, the places that are probably the most important to understand are the low latitudes where the damages are expected to be the greatest and the high latitudes where the climate changes are likely to be the greatest. Without grasping what is going to happen in these two critical regions of the world, we will get a distorted view of the importance of climate change.

We also must understand mitigation costs. I'm amused to hear Dr. Jeffrey Sachs promote at this conference an engineering solution to climate change led by Columbia University. Economists used to be attacked as too optimistic but I guess engineers have us beat. If Dr. Sachs is correct that there is a very inexpensive technological solution that can strip carbon from smokestacks and store it safely, I would agree that it will take care of the problem. Carbon could be safely removed at a reasonable cost and we would simply have to implement the technology universally. But engineers once promised us that nuclear power would produce energy that was "too cheap to meter". This did not turn out to be the case as the technology was more complicated and more dangerous than anyone first realized. I think we definitely need to research new technologies and invest in R&D. Learning how expensive these technologies will be is an important part of the puzzle. That includes estimating environmental costs. The Stern Review is concerned about low probability- high consequence events associated with climate change. The same concerns should be applied to alternative policies. Would placing 500 million hectares of cropland into energy crops lead to world wide hunger? What are the costs of damming the remaining wild rivers? How will the planet store extensive nuclear material safely for thousands of years?

One policy that was not emphasized in today's discussion is emergency plans. What can we do if we are mistaken about climate change and it turns out to be more dangerous than we expected? What actions can we take to immediately cool the planet if we are faced with runaway higher temperatures? Some scientists have discussed the possibility of bioengineering, placing dust particles in the upper atmosphere to cool the planet. This is likely to have unforeseen negative repercussions so that it should not be done lightly. However, if we faced a situation that was considered catastrophic, we should be willing to take reasonable counter measures. I think developing emergency plans that would be implemented only if needed is an appropriate precautionary measure. We should develop the research required to make it possible to implement such plans quickly in case the need arises.

Another point I think that everyone agrees upon is that the planet will warm no matter what mitigation policy we adopt. Clearly, one aspect of climate policy must be adaptation. We must be prepared for the climate changes that are coming. This is going to be especially important for the low latitude countries that are otherwise going to have large immediate damages and the high latitude countries which are likely to see rapid warming. The private sector must be left free to adapt to climate change. The public sector must try to make sure that it keeps up with climate change as well. Changes in dams, coastal protection, water allocation, energy infrastructure are all changes with substantial government input. The government must adapt as needed where it is needed.

Finally, one of the issues raised in the Stern Review is that the damages of climate change will fall most heavily on poor low latitude countries. This raises serious equity concerns that require compensation. The people and firms who emit carbon, who are often wealthy, need to provide compensation to the victims of climate change, who are often quite poor. Specifically, mid and high latitude countries should provide assistance to low latitude countries who are likely to be the primary victims of climate change. Specifically, wealthier carbon emitting countries could provide assistance for adaptation and for development in low latitude countries. The adaptation funds could help lessen the damages in climate sensitive sectors such as agriculture. The development funds could help move the economies away from agriculture and towards sectors that are less dependent on climate and increase standards of living.

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Chapter 9: Scott Barrett, Johns Hopkins University, Paul H. Nitze School of Advanced International Studies

Our chairman, Ernesto Zedillo, opened this session by saying that the wise persons at Davos had declared climate change to be the world's most important problem. He disagreed with this assessment; he thinks nuclear proliferation is a bigger problem; and he may well be right. What impresses me most about climate change, however, is less its importance than its complexity. Global climate change is almost certainly the world's most complex challenge today. It may well be the most complex challenge the world has ever faced.

It is from this perspective that the Stern Review surprised me. Stern and his colleagues looked carefully at this very complex problem and derived a very simple conclusion—that "the benefits of strong, early action considerably outweigh the costs;" that atmospheric concentrations should be prevented from exceeding twice the pre-industrial level; and that the benefit-cost ratio of doing so is about 10:1. To add to my surprise, Stern's conclusions contrast with the mainstream literature. What are the reasons for the difference? There are many reasons, but one is especially important. Stern's conclusions derive in large part from his ethical reasoning.

That ethics should prove decisive may surprise other people, but it did not surprise me. The debate about climate change policy has focused on the science, the economics, and the politics—all of which are important. Perhaps Stern's greatest contribution is to show us (or, rather, to remind us) that the ethics are at least as important.

Where I disagree with Stern is in thinking that the case for "strong, early action" to reduce emissions is as clear-cut as his analysis implies. I am not saying that his conclusions are wrong; I am saying that other conclusions can be supported.

Though Stern recommends urgent action, he also says that, "Only a small portion of the cost of climate change between now and 2050 can be realistically avoided, because of inertia in the climate system." The aim of acting urgently is thus to help future generations. This is why ethics are important to Stern's analysis. He argues that the current generation should take action for the sake of the future.

The generations that will benefit the most from this urgent action will not be born for some time. According to Stern, "Preliminary estimates of average losses in global per-capita GDP in 2200 range from 5.3 to 13.8%, depending on the size of the climate-system feedbacks and what estimates of 'non-market impacts' are included."

These are substantial damages, but over the next 194 years more than the climate will change, and some of these other changes are also relevant to this analysis. One such change expected by Stern is a significant rise in per capita consumption. "In the baseline-climate scenario, 5º C warming is not predicted to occur until some time between 2100 and 2150. By then, growth in GDP will have made the world considerably richer than it is now." So Stern's review urges the current generation to sacrifice for the future, even though the future will be better off.

It may surprise casual readers of the Stern Review that the future is expected to be better off than the present generation. Wouldn't climate change make the future worse off? It would, compared to the alternative of no climate change; but growth, compounded over many decades, increases incomes substantially. Climate change may hit future generations hard in percentage terms, but many decades of growth may be more than able to absorb this loss. Even taking climate change into account, the future can be much better off than the present.

So the question is how much the current generation should assist the future, when the future is expected to be better off. This is where ethics matter. The calculus of this choice hinges on how the benefits of reducing emissions today—avoided future damages—are weighted relative to the costs of reducing emissions today.

There are two ethical components to this relative weighting. The first is how we weight the wellbeing of future generations relative to our own. Are future generations worth any less, simply because they exist in the future? Stern says yes but only because there is a chance that the future will not exist. The possibility of extinction is relevant, but the weight we attach to the future is fundamentally a social choice; it may reflect more than the probability of the Earth being hit by an asteroid.

The second value is how we compare the wellbeing of societies having different per capita consumption levels. These include richer and poorer communities today, and richer and poorer generations. Stern also chooses a relatively low value for this parameter.

A higher value, reflecting a greater concern for equity, would have discounted the future more heavily simply because, in Stern's analysis, the future is expected to be better off. It is this second parameter—this equity parameter—that I shall focus on here.

Though Stern uses a small value for this parameter, his words suggest a deep concern for equity. Stern argues that rich countries should reduce their emissions today to help today's poor countries decades from now ("There is no single formula that captures all dimensions of equity, but calculations based on income, historic responsibility and per capita emissions all point to rich countries taking responsibility for emission reductions of 60-80% from 1990 levels by 2050"), because poorer countries are more vulnerable to climate change ("The impacts of climate change are not evenly distributed—the poorest countries and people will suffer earliest and most."); but he concludes that today's relatively poor generation should help richer generations living in the future.

There seems to be an inconsistency here. The problem is that, in Stern's model, as in all other models of its kind, the only way in which rich and poor societies interact is via emission levels. A different model that allowed rich countries to assist the poor sooner and in other ways would yield a different result. A higher value for the ethical parameter would increase transfers from rich countries to poor countries but shift these transfers away from mitigation and towards adaptation assistance.

My main complaint with the Stern Review is that it chose single values for the two ethical parameters. It would have been better, in my view, had Stern examined a range of values. As I said before, these values are ultimately social choices. Before choosing them, society should be able to examine the consequences of these choices.

In a postscript to his Review, Stern includes a sensitivity analysis—in my opinion, a major improvement. This analysis shows that a higher value for the equity parameter would weaken the case for taking strong action now.

When I say, "weaken," I mean relative to using a lower value for this equity parameter. Importantly, in this sensitivity analysis, Stern introduces a third parameter. This is not an ethical parameter but one reflecting the sensitivity of damages to climate change. A higher sensitivity can offset choice of a higher ethical parameter. This is important to understand: if there is reason to believe that damages will turn up sharply as concentrations rise, then the case for limiting concentrations will not be highly sensitive to the choice of ethical parameters.

Let me, however, return to the equity problem. Is it better to cut emissions today so as to reduce climate change damages experienced by poor countries in the future, or is it better to make other investments that can benefit poor countries today—and, in the bargain, help to insulate them from future climate change? Of course, we need to do both, and Stern would agree with me here, but how should we balance these allocations? They are not separate problems. Investments in adaptation should be co-determined with the emissions path.

Let me give an example of what I mean. Climate change is expected to increase malaria prevalence in the future, mainly by expanding the range of the mosquito vector in higher elevations. Malaria might increase 5 %a century from now because of climate change. Mitigation could only reduce this increase a little bit. By contrast, investment in the R&D needed to discover and develop a malaria vaccine could reduce malaria prevalence across-the-board. It is also likely to benefit the poor countries much sooner. An investment of this kind would help today's poor countries today and not only a century from now.

The example of the malaria vaccine is best thought of as a metaphor for the kind of development that is needed. Investment in treatments and vaccines for the neglected diseases and for R&D to improve agriculture in the poorest countries is also needed.

Stern agrees that adaptation assistance is needed, but his postscript says that this "will come in large part through the delivery of the commitments made by rich countries to double aid by 2010 and the commitments made by many countries to meet the target of 0.7% of GNI by 2015." I have four comments. First, promises of this kind have been made before without being fulfilled. Second, it is not the outlay that matters but the effect on development. Third, and as I said before, adaptation assistance needs to be an integral part of climate policy. Adaptation is a substitute for mitigation. If countries supply less mitigation, they should be made to contribute more to adaptation. Finally, the motivation for providing adaptation assistance would be different than for providing development assistance. The motivation would not be compassion; it would be an acknowledgement of a responsibility to help. The rich countries did not make the poor countries poor, but they are largely responsible for the accumulation of greenhouse gases in the atmosphere.

The Stern Review not only makes the case for strong early action; it also makes the case for limiting atmospheric concentrations. How might we get from here to there? In my view, climate policy must be multidimensional. Five dimensions are especially crucial:

First: I agree with Stern that the richest countries should take steps to limit their emissions now. Different countries may choose to do this in different ways. They may also do this by establishing different goals. This is to be expected, because circumstances vary. However, there will be a tendency for countries to take comparable actions—comparable perhaps most especially in terms of marginal costs. To reinforce this tendency, and to provide a positive setting for goal setting, a declaratory agreement is needed—a treaty in which countries declare the steps they intend to take (Marc Levy calls this, “tote board diplomacy”). The main difference between this approach and Kyoto is that a declaratory agreement would drop the pretense that there would be international enforcement. For this declaratory agreement, enforcement would be internally driven; internationally, it would be helped by “naming and shaming.”

This first step is not enough; it will not stabilize concentrations. To do that, we need to be thinking long term and big. We need, in particular, to be thinking of fundamentally new energy technologies, diffused globally.

How do we raise the bar to this higher level? This is where the second and third dimensions come in.

Second: basic research is needed into new technologies. I do not believe that the incentives for countries to discover and develop these are strong enough for us to rely on unilateral efforts. International cooperation is needed. An example of what I have in mind here is the ITER, the next step in nuclear fusion research, which is being financed by European countries, China, India, Japan, Russia, South Korea, and the United States. We will need a multiple of agreements like this. I my view, developing such agreements should be a priority for climate diplomacy.

Third: we need a means to diffuse the technologies developed by this research. Moreover, this diffusion needs to be tied to the research. There is no point in discovering technologies that will ultimately fail to be diffused.

How to diffuse technologies? There are a number of ways, but one that I believe is especially important is to establish technology standards. Provided certain conditions hold, standards can cause technologies to be diffused without the need for strong enforcement. Establishing these technical standards will require yet more international agreements.

Fourth: as mentioned before, adaptation is also needed. Much adaptation will be undertaken unilaterally. Indeed, in many cases adaptation will be guided by the invisible hand. The big problem is with the poorest countries.

The poorest countries are vulnerable for three reasons. First, most are located near the equator; they are in a sense already “too warm,” and climate change will make them even warmer. Second, their economies are more dependent on the climate; agriculture as a share of income is much higher in poor countries than in rich. Finally, the poorest countries have the weakest institutions. They are the least capable of supplying the national public good of adaptation. Moreover, the market cannot be relied upon to help them. For the same reason that there is almost no R&D into the neglected diseases so we cannot rely on there being R&D that would help to make agriculture in the poorest countries less sensitive to climate change.

Most people think adaptation means raising dikes as the seas rise. But more needs to be done. We need to make poor countries less vulnerable and more resilient to climate change. This requires development assistance now.

Fifth: though not mentioned by Stern, we also need to establish a governance structure for geoengineering. These are engineering projects that can alter the climate directly (an example is throwing sulfur particles into the stratosphere). Geoengineering is the only means by which we can prevent abrupt and catastrophic climate change from occurring, after the first signs of such change appear. I do not believe that geoengineering should be used to limit “gradual” climate change. Its use would create new risks, and it would not address associated problems like ocean acidification. However, geoengineering may be useful for temporary interventions to prevent possibly irreversible abrupt and catastrophic climate change.

The incentives to undertake geoengineering couldn't me more different from the incentives to reduce emissions. A single country can deploy a geoengineering project, whereas no country can stabilize atmospheric concentrations on its own. Geoengineering is also relatively cheap. Indeed, the problem with geoengineering is that a single country may have an incentive to do it on its own and yet all countries would be affected—and not necessarily for the better. It is therefore essential that use of this technology be determined within a global framework.

As I said before, climate change is the most difficult challenge the world has ever faced. It is certainly much harder than was the challenge 45 years ago of putting a man on the moon. Just as President John F. Kennedy said then, however, we should meet this new challenge not because it is easy but because it is hard, "because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win…." The Stern Review has contributed to the global discussion of how to determine the goal of climate policy. After this conversation has ended, we will need to face the practical challenge of how to build and sustain the institutions needed to achieve it.

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Chapter 10: Jeffrey Sachs, Columbia University

Clearly Nick's Review has been having a huge and valuable political effect.

My main question is how much disagreement there really is in the rhetoric of the other panelists at this meeting. This is a bit hard to know, because most of the discussion has been about how fast the world should do what it needs to do in controlling harmful emissions, and about whether the Stern Review is calling for a crash course while mainstream opinion says do it gradually. When I read the Review, I certainly didn't feel that that's really the nub of the issue.

I read the Review's call to action as "Let's get started now, understanding that the job will take decades." There are powerful reasons for putting it that way, because what's entailed is a change in the core infrastructure of the world economy, and this will take several decades to achieve. To do it faster would impose marginal costs that would be extraordinarily hard to justify from the scientific evidence. The scientific evidence, at least as we know it now, suggests that if we act with all deliberate speed right now, planning by mid-century to have completed a huge changeover, we will have been able to keep the dangerous emissions below catastrophic level. According to the Review, stabilizing at 450 to 550 ppm of CO_2e would be possible in such a scenario of all deliberate speed, taking into account the time horizons of demonstration of new technologies and investment in long-lived infrastructure. What is also true is that if we wait another 20 years, then we could no longer, at all deliberate speed, reach the range of 450 to 550 ppm.

One major confusion should, I think, have been straightened out. The Review is talking about 450 to 550 parts per million of carbon *equivalent* (CO_2e), that is, representing all the greenhouse gases in this single number, but all the rest of us are talking about parts per million of *carbon* (CO_2). This is a big difference. I'm quite happy with the 450 to 550 ppm *carbon* target, but I don't have the same confidence in my views about a 450 to 550 ppm carbon *equivalent* level. Scientists at the Earth Institute argue strongly against simply adding the radiative forcing gases to the carbon computation, and for keeping the different types of emissions separate in public discussion and understanding. There are good reasons not to lump the different gases together. They need different prices. They have different systems. They have different residence times in the atmosphere, and it is a bit difficult, I think, to have a target that is a composite of six or more greenhouse gases.

Thus in what follows I will talk about a stabilization target of 450 to 550 parts per million of *carbon*. It would take a profoundly dislocating set of actions to stabilize below this range. And on the other hand, if we start now, it would be possible to stabilize in this range without severe dislocation.

One thing that almost none of the models of climate change formally takes into account is the putty-clay nature of almost everything we live with. Our fleet of automobiles turns over in 20 years; our power plants turn over in 40 to 50 years or a little longer; our residential and commercial structures, in 50 to 100 years. Most things can be retrofit, but retrofitting is much more expensive than investing in the prospective phase, whether for decarbonizing energy or for reducing emissions in other ways. So the low marginal cost pathway is one that takes the easy wins, where they can be found (and there is a lot of waste in the system), but invests as old capital is rolled off and new capital is rolled on.

Most importantly, this applies in electric power. To decommission existing well-functioning coal plants right now, and build wholly new power plants, would be a huge and really expensive change. If we insist, instead, that as power plants are moth-balled and new ones are built, they should satisfy the constraints of being carbon-effective or carbon-efficient, we shall be able to manage the transformation at a much lower marginal cost. Gigawatts of power plants are being built right now with old-fashioned coal-fired thermal technology all through China, India, and a lot of the rest of the world, threatening to lock us into a time path that will be devastating. But if we get started now—so that as capital is reinvested it is invested in efficient ways—the marginal cost of the needed transformation will be quite low.

My view is that the marginal cost of the transformation is going to be considerably lower than in Bill Nordhaus's model, which I take to be the state-of-the-art work-horse model of the profession. (Whenever I disagree with Bill Nordhaus I worry intensely about why that might be, because he is about the most reasonable person I know.

And, so, I have spent a lot of time in the last few months, as he knows, sending him e-mails to try to understand the assumptions underneath the DICE model.)

My view is that even when using the DICE model, you must still put in the right parameters to have it come up with sensible answers. When you run the DICE model with what I think are more realistic parameters than those Bill has used, the debate on the Stern Review turns out not to be very much about the time-discount rate, or other profound features of the approach, but chiefly about the parameters that one is assuming—mainly about the costs of abatement and about several basic features of the world economy.

I apologize in advance if I have this wrong. As mentioned, I take the Stern Review to be saying "Let's get started seriously now, and reach the year 2050 with the chance of ending the century at 500 or 550 ppm and no higher." In contrast, Bill's model says, "We can be more gradual. We should make the adaptation over two centuries, and we can breach 550 ppm. Maybe we'll go to 600 or 700, and that's the right thing to do. Eventually, we will stabilize, but we don't have to do this within a century, and we don't have to do it within the limits that Nick is talking about." So I tried to understand the source of this difference.

The DICE model adopts a baseline path of emissions that is quite a bit lower than the rest of us have assumed. Under Bill's baseline of no control, atmospheric concentrations only reach 610 ppm of carbon by 2100. I know of no other model that uses such a low level. But if that's your baseline, you don't feel urgent about control because the world's already more or less controlling these things for you.

The underlying reason seems to be four assumptions in the model. One is that the assumed baseline economic growth rate is only about 2 % or so. This seems to me too low a basis for policy decision making, because it is reasonable to presume that China and India are going to grow quickly, and produce a lot more carbon than now.

Second, the population assumption is far outside the norm. It is for 7.7 billion by 2050, whereas the UN's median forecast, which—right or wrong—I would take to be a better one on which to base an assumption like this, is 8.9 billion.

Then there are two economic assumptions. One is that a good deal of automatic decarbonization goes on over the long term. (This is a better assumption than in an earlier variant, which assumed 100 % automatic decarbonization at no pain in three centuries.) Now the assumption is that after substantial decarbonization, by the end of two centuries you arrive at a point where you don't really have to control emission levels because technology at zero marginal cost controls a lot of them already.

The fourth point, and the nub of the issue, is that the assumed abatement costs in the DICE model are much too high. I think that in the discussion over the last ten weeks we have focused too much on the discount rate, as if that is the only thing really going on. What seems to me to be even more important is the assumption on the cost of cleaning up. In the DICE model, the parameter for abatement costs varies over time but implies that, as of mid-century, 100 % abatement would cost 3.9 % of GNP and 75 % abatement would cost 1.7 % of GNP. I am living among technological optimists in the Earth Institute, in a world of engineers, who think that that 1.7 % is roughly five times too high. If you change this assumption and say that you can do 75 % abatement at something like 0.6 % of GNP, you get a completely different estimate of the cost of doing what is needed, and this has nothing to do with the time discount.

Now, here's my attempt to put in an alternative set of estimates.

…My colleagues at the Earth Institute place a lot of hope in certain technologies. One is nuclear power: whether we like it or not, China and India and many other places are going to go nuclear, and this will solve a lot of the emissions problem at quite low cost, maybe even at zero marginal cost compared to a baseline of thermal power.

Carbon capture and sequestration (CCS) is the second obvious technology. The IPPC *Special Review on Carbon Dioxide Capture and Storage* judges it extremely likely that there are enough sedimentary geological sites to safely sequester gigatons of carbon dioxide. IPCC gives a cost estimate of \$10 to \$30 per ton of CO_2, or roughly one to three cents a kilowatt hour for electricity, so this is a proposed technology with a very low marginal cost. We do not know yet whether it works; I think the mechanics are quite well understood but the geology needs to be proved. And, so, if I were choosing a decision right now, the first thing I would do would be to build some prototype CCS plants and have geologists measure tracer gases coming out of the deposits to see whether they are leaking or not. If we cannot do carbon capture and sequestration, we have a real problem: the next-best technology is a lot worse than this.

But if carbon capture and sequestration works—that is, turns out to be stable geologically—the world will face prices of \$25 or \$30 per ton of carbon dioxide, on the margin, for maybe up to 60 or 70 %of the total abatement in the economy. And CCS would also allow another significant change: the conversion of existing local site-based fossil fuel users like furnaces and boilers into users of electricity that is cleanly produced. The costs of that kind of that conversion—say, for home heating, away from oil or natural gas to heat pumps powered by electricity coming from a clean power plant—are quite favorable as well.

As regards automobiles—another major area needing huge improvement—we already know that a plug-in hybrid system can work off the existing infrastructure and probably at quite low cost. The social cost may even be zero or negative, because you trade off higher battery costs against lower petroleum or carbon costs, and the net trade at \$60 a barrel of oil is favorable at any fairly low interest rate. There may be zero social costs to switching over, if consumers see the hedonic aspects of plug-in hybrids as acceptable.

The point is, there are technologies applicable on a large scale (not to mention, say, cellulosic ethanol and other biofuels, and solar energy) with huge potential.

What is the bottom line of all this? If you assume that all of the CO_2 that needs to be disposed of can be disposed of at \$25 dollars per ton, on average, the cost of doing this is only 0.3 % of world GNP. The technologies just mentioned, from plug-in hybrids to CCS and nuclear power, each imply costs of \$25 to \$30 per ton of CO_2 or less. Some simple experiments show that if you allocate the rights to emission on an equal per capita basis, for example so that the 0.3 % of world GNP is to be paid more by the rich countries than the poor, the US cost turns out to be about 0.7 % of US GNP, assuming a \$25 per ton carbon dioxide abatement cost.

If these cost estimates are right, they suggest two very simple policy prescriptions: to put on a \$25 tax per ton of carbon for the next 40 years and to undertake research, development, and demonstration projects. Our models will never show us whether a technology works or not; we shall only learn this by testing in real life. And we need demonstration projects more than anything right now, because we have close-to-market technologies that need to be demonstrated. If we do these two things, my guess is that we shall see a massive conversion of the power sector, especially in the rapidly growing developing countries.

This is the essence of the story: we cannot calculate the cost of abatement from economic models, but only from thinking about how to promote a system of technological change. So we as economists need to talk to engineers much more than we do now, to understand the options and what their marginal costs are. The technology is not very expensive and not likely to be so. The chances for major technological improvements are enormous at present. If you ask me whether engineers could make energy far more efficient, I would doubt it. But I would say yes, they could decarbonize, because this is a new problem. And there are so many margins to work on that the marginal costs of decarbonization are going to be quite small.

I will end with a prediction. This is that by 2010 we shall have a post-Kyoto international agreement that has a globally agreed target for mid-century on CO_2 ppm (not CO_2e ppm), of perhaps 500 or so, aiming to stabilize at less than two times the pre-industrial carbon level. My guess is that in 2008 all American presidential candidates will have a very strong climate change policy in their platforms. At the political level, we'll enter into post-Kyoto negotiations in December 2007 at the conference of the parties of the UN Framework Convention on Climate Change in Bali in December. That will open a debate that will last through the US presidential elections and through the Chinese Olympics. Nothing is going to happen in 2008 on this. And then, in 2009, there will be a new US president. There will be post-Olympic cleanup and hangover, and the US, China, and India will agree on how to share the costs of doing this. And in 2010, the post-Kyoto protocol will be signed. It will take two years to ratify, and go into effect January 1, 2013.

Chapter 11: Reaction to the Panelists: Sir Nicholas Stern

Thank you all very much for the comments. Many of the points I will make, and several others, are made in depth in the respective sections of the Review and in the publications since its release which can be found at www.sternreview.org.uk.

A: The Role of Integrated Assessment Models in Policy Analysis

I'll begin my reply by first explaining at the rather broad level of where these kinds of models take us and then comment briefly on some specifics of the parameter values.

The reason I want to start at the broad level is that I would be very surprised, indeed deeply worried, if a policymaker thinking about these issues decided that everything turned on whether the elasticity of social marginal utility, η, equals 1.1 or 1.7, or on the very close details of pure time discounting. The first thing to do is to step back and ask yourself what kinds of risk reductions you can get for an expenditure of around 1% of GDP per year. Most people would be able to understand that question, and they'd be able to look at the risks in a much more subtle and informed way than is possible in the kind of aggregative models that we build. So the first way to look at the climate change problem is in terms of common sense judgments where you compare costs on the one hand with reduced risks on the other, and where you can be much more subtle about the reduced risks than you could be in the model. I have already emphasized the severe limitations of this type of modeling and economists do the profession and themselves a disservice if they suggest that our whole policy analysis turns on model specifics.

The second thing is to look at what really matters among the statements that come out from the analysis using the model and ask how robust those statements are. The statement that really counts is that the cost of acting strongly now is a lot less than the cost of the damage that is saved or averted; that statement is robust. The particular numbers are of much less significance to the argument.

We did provide sensitivity analysis in the postscript to the Review. (This was published on the Web about three weeks after the report itself, and is also in the bound version of the Review that is published by Cambridge University Press.) That sensitivity analysis shows that in the context of the model used that key statement is very robust except for extreme forms of pure time discounting. The postscript shows that, if you raise the value of η up to two, or a bit more, most of the model-runs confirm the statement that the cost of the action to avert the damages is a lot less than the damages averted.

B: Ethics

A common misconception is that the Stern Review uses this or that discount rate. In fact, one of the key features of the approach in terms of an expectation of a utility integral is that the discount rate is endogenous. There will be many discount rates depending on the period of time and the path. And for non-marginal changes we must go back to the objective or welfare function. Generally discount rates are derived in the special case of the evaluation of marginal changes. Let me give two examples of the relevance of this endogeneity. Climate change impacts are uncertain. Accordingly, the discount factor (whose rate of fall is the discount rate) used will, for example, be higher for outcomes with limited impacts than it is for projected outcomes that erode consumption more significantly. Second, a higher growth projection will increase in the discount rate but will bring forward in time absolute climate change impacts.

By explicitly stating and quantifying assumptions, the Review has helped clarify the ethics and we welcome the discussion the Review has stimulated. There are, and should be, genuine differences of opinion on ethics and that is why we provided sensitivity analysis. But ethics must be discussed and should not be seen as arbitrary. As already noted, we found no persuasive arguments to discriminate on the basis of birth dates. This would indeed be ethically arbitrary and constitute little more than a failure of the imagination. More importantly, it accords with what most people understand as an ethical system of valuation. By contrast, to use market interest rates to derive ethical values is misplaced. It fails to make for either a 'prescriptive' or even a 'descriptive' account of value judgments. Market rates are derivative of investment, saving and consumption decisions of individual consumers and producers, made primarily with a view of personal gains within expected lifespans. They do not give an indication of broader ethical valuations of communities thinking of how they should treat the interests of future generations. Market information can be relevant here but it has to be used very carefully and assumptions made explicit.

On eta, the elasticity of social marginal utility, we would accept the possibility that some would suggest an eta greater than 1. Note however that this would accord with a degree of altruism that some would find surprising. Using eta (η) = 1 implies that an increment for someone with five times less resources than someone else will be valued five times more (u′(c) = 1/c). Some commentators have suggested that higher values should be used. Using $\eta = 2$ would mean that an extra unit to the person five times poorer would have a value twenty five times higher (u′(c) is the reciprocal of the square of c). However, as Dasgupta has noted, there are arguments relating to 'responsibility' for damages that might imply the use of a higher eta than would be the case if we focused merely on the ethics of 'compassion'. In terms of estimating the value of climate change damages, a higher eta would raise the discount factor but also increase our aversion to risk. The net impact on valuing distant but risky outcomes is ambiguous and this is shown in the sensitivity tables produced after the review. For example, we have shown that for eta higher than 2 and with the possibility of catastrophic scenarios, the estimate of the value of damages will rise with the elasticity of social marginal utility[5].

C: Alternative Strategies and the Structure of Risks

It is important to note that the estimates of the damages climate change are just as sensitive to small but plausible changes to the climate damage sensitivity parameter than they are to discounting assumptions. In so far as we have adopted what may turn out to be a conservative or optimistic view of the damages, the chances are that our damage estimates may prove to be understatements. It is worth restating for the record, that although we have gone further than many previous studies in measuring what counts, there were many aspects of the story that we simply were unable to explicitly value. These include the damage from socially contingent impacts such as conflict and

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[5] For example, setting η to 3 has little impact on the numbers due to aversion to the worse case scenarios (see Dietz, S., C. Hope and N. Patmore (forthcoming): 'Some economics of 'dangerous' climate change: reflections on the Stern Review', Global Environmental Change., forthcoming and Stern, N. (2007a): 'The case for action to reduce the risks of climate change'. Paper A of 'After the Stern Review: reflections and responses''. February 12th, 2007. Working draft of paper published on Stern Review website: www.sternreview.org.uk). Essentially because η captures aversion to risk as well as aversion to inequality.

migration, and the treatment of Knightian uncertainty – that is, our aversion to ambiguity when we know we are entering "unchartered territory".

Obviously one way to approach policy is to put the climate change problem to one side: "We'll make these wonderful rates of returns on these investments that we can see, and we'll sort out climate change later on." Would that leave us in a good place? I suspect not. As people become richer and environmental goods become scarcer it seems likely that their relative value will rise rapidly, giving a greater weighting to many of the climate-related damages. And as we all know from the basic theory of discounting in models with many capital goods (following from Malinvaud's famous article in 1953 *Econometrica*) the unit of account that you use has a very striking effect on the discount rate. If you did your accounting in environmental goods, indeed the discount rate would probably be negative. So, if you build models in which you underestimate the rapid rise of the price of environmental goods relative to other goods, then one way of compensating for that mistake is to use a low discount rate[6].

It is important to note that the flow-stock nature of GHG accumulation plus the powerful potential impact of climate change will render many consequences irreversible. Thus exploiting an arbitrage opportunity between ethical discounting and market rates by investing elsewhere and using the resources to compensate any later environmental damage depends on narrow and implausible assumptions and may be very cost-ineffective and highly risky.

D: Social Costs of Carbon and Radical Policy

I'd like to say something about what "radical" means. If you remember the argument this morning, I said go for a stabilization goal on the basis of risk management and the cost of getting there, think of the choice of paths that are consistent with that stabilization goal, use the price mechanism to decarbonize within that framework, and revise from time to time, bearing in mind things like the social cost of carbon. From this point of view, you've got to ask what "radical" means. I don't measure radical in terms of the social

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[6] There has been some explicit modeling by Sterner, T. and Persson, U. M., (2007, An even Sterner Review: Introducing relative prices into the discounting debate. Working draft: http://www.hgu.gu.se/files/nationalekonomi/personal/thomas%20sterner/b88.pdf) that shows the powerful effect that this can have on the modelling

cost of carbon, which is very hard to measure and, of course, depends very much on your choice of path. (On the path that we used for stabilization at 550 ppm carbon dioxide equivalent, the social cost of carbon started at $30 per ton of CO_2, though it would have been higher on the business-as-usual path.)

There seems to have been some confusion over the carbon tax level people believe we are advocating. Professor Nordhaus quoted our business as usual level of $85 per ton. However, this is not what we advocated and if adopted would change the business as usual path. Thus the costs would be lower as imposing such a price would drastically reduce emissions and the damages that would result. Professor Cline used our average mitigation costs as our suggested rate. We would not advocate this either. We should note that whilst marginal damage costs are only one relevant aspect of a carbon price, they are important and they are likely to rise over time. The relationship between average and marginal costs of mitigation is discussed in more detail in Chapter 9 of the Review. In Chapter 13 of the Review we justify our policy goal of stabilizing emissions between 450ppm and 550ppm CO2e. In this range we estimate the social cost of carbon to be between $25 per ton (450ppm) and $30 per ton (550ppm) and so policies should be broadly consistent with this range. However, in distorted and uncertain economies any tax should be different from an SCC[7]. Generally the SCC is not a reliable measure of the 'radicalness' of policy.

Instead of discussing particular social costs of carbon I would talk about radicalness in policy in terms of the kinds of targets you set yourself for reducing emissions over 20 and 50 years. I would ask what targets the European Union will set itself for reducing emissions in the third phase of the emissions trading scheme between 2012 and 2020. We're talking in Europe about a 20 %reduction no matter what anybody else does, or maybe 30 %if countries elsewhere move strongly, and we wait in strong anticipation for the United States.

That's the kind of way I would measure radical. Then the questions are: How difficult is it to reduce emissions? What kind of things would we have to do? Is it easier if

[7] See the literature on modern public economics (e.g. the Journal of Public Economics) and Section A7 of Stern (2007a): 'The case for action to reduce the risks of climate change'. Paper A of 'After the Stern Review: reflections and responses''. February 12th, 2007. Working draft of paper published on Stern Review website: www.sternreview.org.uk

we start now? And I actually think that starting now is in some ways less radical than starting later because if you start now, you can spread your action out over a longer period. If you postpone the decision but subsequently decide that the stabilization goal of 550 ppm is wise, then you get yourself into much more trouble later on.

So, I would see radical in terms of the kinds of actions you have to take, the kinds of quantitative goals you have to set, the kinds of R&D you try to do now. That's my notion of radical. And I suspect that if Bill Cline and I looked at radical in those terms, the two of us might come up with similar kinds of ideas, and the policies we would describe would look rather similar.

E: "Political Constraints" and Peer Review

One or two people have mentioned political constraints. They appear to know things about where and how we worked that are totally at variance with the experiences of those of us who were there. The team and myself didn't know what the conclusions would be before we started. I didn't feel under political pressures. Certainly once you're operating in a political environment, there is a limit as to how much you can share, because of the way the argument starts to take place in the newspapers rather than amongst analysts. That's a constraint on the process, but it's not a constraint on what you actually say at the end. So, I didn't feel political constraints. I certainly felt a time constraint. That was painful, and I would like to have continued to take the analysis forward. I look forward to doing that when I return to academic life.

On the point of peer review, the Stern Review was an independent review that was commissioned by and reported to the UK Chancellor and Prime Minister. UK Government does not undertake peer review on commissioned reviews so this was not an option. We did hold a full call for evidence that provided some significant contributions (available on our website). We published papers outlining our approach as it developed several months before publication and gave many presentations around the world that made our emerging thinking clear. Stakeholders were engaged throughout the Review and we drew from the vast wealth of peer-reviewed literature, as the IPCC does in its own process. In an area such as climate change, a subject in the media spotlight, there are risks of early confused coverage if the Review's contents were somehow leaked.

While the Review did seek to build on the foundations of the academic literature on the economics of climate change, its target audience was not only academics but also policy–makers, business and individuals. This diverse audience means that reviewing the document from only an academic perspective may have reduced the impact on other audiences. One of the things that has pleased me most since the release of the report, is the diverse range of people from around the world that have engaged with the report.

In many ways some peer review has been carried out since the Review's release in the public domain: today has been an important part of this process. The Review has been given the attention of many critiques, many of which we have responded to. I believe throughout this process that our analysis and conclusions have proven to be very robust. Most of the attention has focused on ethical valuations on which reasonable people can differ, but we give powerful arguments for the ranges selected for examination. Many of the other comments are based on misconceptions and false assumptions about what the Review did or failure to read the whole report. So, fortunately, there is nothing significant that I would change if this peer review had been conducted before the release of the Review, other than to include the sensitivity analysis for Chapter 6 (contained in a Postscript and subsequent analysis) in the main body of the Review and to signpost the content of Chapter 13 in Chapter 6 for those that did not have time or inclination to read that far.

F: Additional Points

I think many comments, including those by Gary Yohe and Rob Mendelsohn, ignored the basic sensitivity analysis that we applied. As I mentioned earlier, this showed that you can change the values used in the formulation without changing the key statement of the first half of the Review the costs of action are much smaller than the damages they avert. If you don't like η (elasticity of social marginal utility) equals one and δ (pure time preference) equals 0.1, then increase η to 1.5 or so. You get the kinds of rates of return that you apparently think you see as social rates of return in the market, (although how you appear to know these social rates over hundreds of years puzzles me, as I revealed earlier) and you reduce the weight of the benefits at the far end that you don't like when η equals one, and you still get the same basic conclusion: that the damages saved are substantially greater than the one %of GDP that it costs to save them.

On comparing GDP and consumption, there is no problem, because we measured the cost in terms of the percentage of GDP, which acts just like a price index that applies to both consumption and GDP. If you're looking at long-run steady states, then there's no difference in percentage changes between GDP and consumption. So, if you're looking at the long run and, eventually, roughly balanced growth, as we were, there is not a problem in comparing these metrics. We did put a paper up on the Review Website (Paper A of 'After the Stern Review: reflections and responses' www.sternreview.org.uk) at the beginning of February in which we looked in detail at the suggestion that there was some kind of inconsistency between those two things, and not surprisingly, we found that there wasn't.

The "now and forever" language in our report is accurate but perhaps it wasn't particularly felicitous, and on reflection, we might have used some other wording. But the point is that we are using a balanced growth equivalent, which is quite a useful tool for comparing percentage damages saved and percentage costs over time as it can capture pathways using a single comparable unit.

On Gary's point on the stabilization target, it was through looking at where we are now and the costs of benefits of stabilization at 550ppm CO2e that we suggest that policy should aim to stabilize between 450ppm and 550ppm CO2e. There is little modeling evidence of lower targets but we were clear that the target should be below 550 ppm not at 550ppm.

Moving now to Rob Mendelsohn's point, unfinished business this certainly is. There would never be any pretense of having the last word. How could there be? And that's not where we try to be.

We have been very open and clear on the analysis undertaken for the Review and will continue to be so. Suggestions of problems of reproducibility are contradicted by the modeling undertaken by members of the panel that uses our parameters in other models and in some cases gets similar results.

Now, what about the charge that we are comparing mitigation policy with no mitigation policy in a fashion similar to comparing education policy based on a world with schools with one with no schools, and that sort of thing? This is dead wrong. I honestly don't think that's the right analogy for what we did. The trouble with writing 700 pages is that people don't always read it all. I apologize for that, but we do in Chapter 13 offer a fairly detailed discussion of the way in which calculations of damages have to be put together. And Chapter 13 is not hidden. It is clearly the concluding chapter to the first half of the Review[8].

Chapter 13 clearly addresses this point and several others Rob made earlier and the strategic argument that we were making using the model was similar to the strategic argument I started off with today: that when we're talking about stabilization levels, we should be thinking of something *at or below* 550 parts of CO_2e per million. We are not saying 550 or nothing. We are saying "Here are very good arguments for coming below 550. Where below 550, we don't know." We heard the discussion this morning that 550 is outrageously high. But 450 is already probably very, very hard to achieve, so the choice is somewhere between 450 and 550. Thus we used both the intuitive risk reduction approach and the modeling approach to say that the target level should be below 550, and we left open where below 550.

The cheapness of mitigation is an area that benefits from a closer look. I'd simply remark that, a month or so after we published our report, the International Energy Agency investigated the technological options in rather greater detail than we were able to do and came out with cost estimates that are below our own.

Rob Mendelsohn said several times that the Review assumes this or that about different technologies. Again dead wrong. Actually we just give examples of the alternative kinds of portfolios that might yield these kinds of cost reduction. The work looking at technological possibilities was led by Dennis Anderson, Professor of Energy Policy at Imperial College. We emphasized very strongly that the portfolio should hinge on a strong price of carbon and strong investments in R&D. That was one method we used. The other was to survey all the various abatement cost estimates in the literature; Terry Barker, who did this for us, came up with an estimate of around one %of GDP, though there are a lot of estimates out there.

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[8] http://www.hm-treasury.gov.uk/media/A/2/Chapter_13_Towards_a_Goal_for_Climate-Change_Policy.pdf

Briefly on Rob's other points on mitigation costs. The assumptions on learning are modest and well below historical levels. In Dennis' modeling costs are discounted as they will be assessed – using market rates. Constraints are placed on the potential of each technology and estimates of cost do include capital costs. If mitigation reduces the cost of fossil fuels many would see this as a benefit since the main change will be a reduction in their rent which is merely a transfer and not a resource cost. The major problem with our mitigation costs is not in all the ways Rob suggests. Given that they ignore the co-benefits from energy security and local environmental effects, which in some cases may entirely offset mitigation costs, they are likely be too high[9]. There are some cases where climate policy does not work together with these goals but on the whole there are significant gains to be made beyond simply those in terms of avoided climate change.

G: Conclusions

Finally, on "radical" or "dramatic" again: if you start now and spread your action out over time, there is less drama than if you wait, and then get yourself in a difficult situation from which it's very difficult to escape. And I think to "wait and see" and potter on up to 650ppm would put us in an extremely difficult situation. Then action would start to get dramatic. It's much less dramatic if you start now and reduce emissions in a measured way with a target like 550 ppm in mind.

At 550 ppm there is still a small chance of getting near 5 degrees Celsius eventual temperature change relative to pre-industrial. At higher concentrations this chance becomes increasingly likely until about 800 ppm when it becomes the central estimate. Such changes would take us way outside the realm of human experiences and will challenge the fundamentals of life in many regions especially where conditions are already difficult such as Africa. Significant parts of the world will become uninhabitable because of peak temperatures, desertification and drought or eventual sea level rise. The threats of extreme weather events and shifts in the world climate system would become very severe. Those that suggest that the Review's message was radical should be clear what policies they recommend, the concentration levels this would take us to and the

[9] They do assume that effective policies are put in place. Costs are likely to be higher if the policy considerations in the second half of the report are ignored.

risks we face as a consequence. They should be clear, as we were, about what risks have been omitted from their analysis. They should also justify whether they believe that the risks of these levels of temperature change are in fact small or whether they believe that they are large but we simply don't care about them because they are in the future.

Most of the key points in the commentaries on the Stern Review have been discussed today. To conclude below is a bullet-point summary of my response to the main points that have been raised in relation the Review's central conclusions.

1. The costs of stabilizing the stock of GHGs in the range 450-550 ppm CO_2e are considerably less than the costs of delayed action. This conclusion is robust across most reasonable perspectives, including parameter variation within formal modeling.
2. The policies proposed by the Review to stabilize within this range are sound and based on strong economic principles, which move beyond the previous literature in important ways, concerning risks and ethics and constructing an international 'deal'.
3. The Review's foremost argument for strong action is based on a detailed, disaggregated assessment of the risks of business-as-usual (or of delayed action) in various regions and on various dimensions. The types and scale of risks involved were confirmed by the IPCC's *Fourth Assessment Report* a few months after publication of the Review, thus dismissing early claims by some that we exaggerated the risks, and by others that we understated them.
4. The costs of emission reductions to stabilize within the above range were estimated to be around 1% of world GDP, although there is a margin of uncertainty, as emphasized in the Review. Commitment now, clear medium- and long-term objectives, and good economic instruments will control these costs. The Review's cost estimates are consistent with those from the Global Energy Outlook of the International Energy Agency, published subsequent to the Review at the end of 2006 (IEA, 2006), thus countering claims by some that we underestimated the costs of adjustment.

5. The second, and supporting, argument for strong action is based on integrated assessment modeling, which implied high costs of inaction under a range of reasonable variations in assumptions.
6. Critics have focused on the formal modeling in a way that shows naïve understanding of the appropriate use of such models in policy debate. In the very long-term and complex context of climate change, such models cannot be of sufficient plausibility to provide the main argument.
7. Misleading and mistaken criticisms of the Review include a whole range of casual misreadings or simple errors – many examples were given in the Appendix to an article in the journal World Economics[10].
8. Discussion of discounting by some commentators has been confused (with one or two important exceptions) and has shown a weak understanding of the basic theories of cost-benefit analysis and the applied theory of policy:
    a. Discount rates are essentially marginal concepts and climate change is a very different problem involving non-marginal change;
    b. There is no market which reveals the preferences of a community considering responsible action over many generations. Thus whilst we can think about the usefulness of some market information we cannot observe directly the appropriate discount rate;
    c. We have not seen a serious ethical argument for a high rate of pure time preference in this context of planetary risk. Further, there is no contradiction between the application, on the one hand in climate-change policy, of a very low rate of pure time preference to the intergenerational comparison of welfare, and on the other hand in the appraisal of shorter-run and marginal projects, the application of higher rates to account for the possible collapse of the project environment;
    d. An elasticity of the social marginal utility of consumption, η, of 2, looks inconsistent with many distributional judgments in practice, but values around growth 1.5 are indeed plausible

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[10] Dietz, S., C. Hope, N. Stern and D. Zenghelis (2007). "Reflections on the Stern Review (1): a robust case for strong action to reduce the risks of climate change." World Economics **8**(1): 121-168. http://www.hm-treasury.gov.uk/media/E/8/World_Economics1.pdf

   e. Faster growth gives not only a higher discount rate but also earlier emissions and thus earlier and higher damages;
   f. There is no contradiction between the Review's discount rates and current rates of savings once the structure of growth (in particular technical progress) is taken into account.
9. The key arguments and conclusions of the first half of the Review remain strong. The reasons we come to different results from some earlier literature lie in using modern science, and being serious about risk and ethics. From this perspective, some of the earlier literature is now seen to be badly misleading.
10. Those who deny the importance of strong and early action should explicitly propose at least one of three arguments: (i) there are no serious risks; (ii) we can adapt successfully to whatever comes our way, however big the changes; (iii) the future is of little importance. The first is absurd, the second reckless and the third unethical.

Stern Response to Presentations by Panelists Scott Barrett and Jeffrey Sachs

I accept Jeff's point about differences between the various greenhouse gases. It is important to recognize the difference between their impacts and ensure that this is reflected in policy. However, there are potential efficiency savings from ensuring that there are similar price incentives across the gases relative to impacts. Pulling these gases together helps draw attention to the importance of the other greenhouse gases. It also highlights the full temperature change that we risk rather than the smaller changes if we only consider carbon dioxide.

Regarding Scott's discussion on the difficulties on building international agreement, I feel that our analysis in Part VI of the Review on International Collective Action is very pragmatic as well as theoretical. There is a strong focus on the importance of getting international buy-in from China, India and other developing countries. To get action countries must be committed to any targets and believe that this is the best course of action. Countries cannot be forced into compliance and it is difficult to envisage a global institutional architecture that can force countries to act. Fortunately change is now being driven by the will of the domestic population to do the right thing and by visionary leaders. In my discussions with key stakeholders in India, China and elsewhere there is recognition that they have something to lose and this gives me hope for the future discussions.

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

However, whilst adaptation is necessary and sensible it is important to recognize that it is not a perfect substitute for mitigation and is likely to become increasingly expensive. Adaptation can only mute the impacts of climate change; there are limits to what it can achieve. Impacts on ecosystems, for instance, may be impossible to avoid. This is particularly true at higher levels of temperature increase, where the impacts will be more severe, and the risks of abrupt irreversible impacts higher. Mitigation is the only way to reduce these risks.

Regarding what Scott said about the importance of acting to support developing countries in their development, including, for example, on malaria. I would be there and have been there, and I agree entirely.

My only other remark here is that we know that whatever we do to reduce climate change will not solve the poverty problem in poor countries: however much we deliver on the aid commitments already made, poor countries will still be much poorer than we are over the next 30, 40, 50 years. Basically, what will pull them out of poverty is their own actions, but there are things that richer countries can do to help. We should act to support developing countries in their plans for development, but this will still leave the problem of inequality pretty severe.

Chapter 12: Panelist Responses

WILLIAM NORDHAUS:

Politicians will do their own thing, but we have our own responsibility to get the economics and science right. I'll just suggest three areas.

The first is on what I'd call high resolution and high frequency science. A striking thing about the latest IPCC report is how little the baseline scenarios have changed since the first report was published. But at the edges, there are major issues: abrupt climate changes, issues of glaciology, of tempestology—hurricanes—and of regional resolution. These are some of the fine-grained details that are the tails of the distributions that we talked about earlier. We social scientists are downstream: we collect the debris from science as it comes by us, the good models, the bad models, the good studies, and the bad studies. But, basically, we can't get anywhere without high resolution and high frequency science in this area.

For social science research, I'll mention two issues. First, the scenarios that are now being used for the climate models are inadequate. They're the SRES scenarios (from the *Special Report on Emissions* of the Intergovernmental Panel on Climate Change), which are ten years old in their conception and emerged not from a committee or even a review, but from international negotiations. There is a need for serious long-term modeling of energy and the economy using a multi-country approach—not these little reduced-form models that you've heard about today, but serious modeling. Second, we understand less than we ought to about how technological change is induced, about what we call, in technical language, endogenous technological change. We don't have a firm understanding of how to encourage green technologies, of the role played by the market versus government subsides, government tax credits, and government performance. This is an area we need to study more.

Finally, in political science and law, our conception of what is needed is very limited. There's virtually nothing for guidance except for Scott Barrett's work on the political economy of international agreements. Though we know a lot about the political economy and legal aspects of international trade, for example, we have a far less robust basis for making international environmental agreements. The Kyoto Protocol, I think, was recognized in 1997 as a conceptual disaster; it has no coherence politically or economically or environmentally. We also have to recognize that it is the outcome of bargaining, of a complicated set of negotiations among major parties. I think in the climate change area, a better conceptual framework for negotiating is absolutely critical to an understanding of how we go beyond the current inadequate arrangements.

WILLIAM CLINE:

First, I would like to see some research on whether we really expect the beginning of a reversal in atmospheric concentrations, as Nick Stern just said, after a 200-year time horizon.

Second, what kinds of probabilities and what gross quantifications of economic cost could one attach to seven meters or more of sea-level rise from the Greenland and West Antarctic ice shelf?

GARY YOHE:

One of the illustrations in the Stern Review is a matrix (crafted by Tom Downing and Paul Watkins) that has uncertainty on one axis and valuation metrics on another. Under uncertainty, it goes from projection to bounded risk to true surprises. Under valuation, it goes from market to non-market to social valuations in multiple metrics. The upper left-hand portion of that matrix has some numbers in it. And the lower right-hand portion has almost nothing in it. The right-hand column is almost vacant. The surprises part is almost vacant. You would be enormously surprised, perhaps, to learn how hard it is to get the scientific community to give us descriptions of what the impacts of global warming will be, and even to give us some idea of what we should monitor, and how timely the signal would have to be, for the world to avoid going over particular thresholds. As economists we need that sort of information if climate change is a risk problem. We need to know what happens in the tails. And if the tails are thick, we need to have some idea about their thickness and how far out they go.

In the definition of policy, there's a tension between, on the one hand, a policy environment that adjusts to new science as it comes on-stream and aims at goals that we believe are appropriate, and on the other hand, policy that's predictable, persistent, and sets a stable environment within which investments can be undertaken. I don't think we know very much about that specific tension in policy design.

ROBERT MENDELSOHN:

We've spent a tremendous amount of money on the natural science part of the climate-change debate, linking energy use to final changes in temperature. We have spent very little looking at other aspects of the debate and, in particular, on the damage side, we've looked at very little that connects changes in temperature to actual damages. We know a little bit about what's going to happen in the United States, but much less about the rest of the world.

I also think it is very important to study high-consequence low-probability events. Scientists have predicted these, but there's virtually no social science analysis of what will happen if one actually occurs.

If there were a very inexpensive technological solution to climate change, I agree with Jeff Sachs that that would be the end of the story. But engineers have made mistakes in the past about how optimistic we should be about some technologies (such as nuclear power that was going to be too cheap to meter). And so it is very important to look at some of the proposed abatement technologies and see how feasible they are, and how expensive they're going to be.

It's also important to look at hidden costs and unexpected consequences. Abatement technologies have hidden environmental costs, and some of the things we're considering doing to stop climate change may have unexpected consequences. For example, suppose we do dramatic carbon sequestration and put all this stuff down in a pit and 20 years later it's all back in the atmosphere? That's a policy with no beneficial effect whatever. So, we need to study those things very carefully and try to understand what the consequences are.

One thing we definitely should develop is an emergency plan, some actions we wouldn't normally consider but would take if climate change turns out to be a lot worse than we expected and is running away from us. For example, we probably wouldn't want to send particles up into the upper atmosphere just as a regular policy. But if our alternative is catastrophe here on the planet, then we want to have policies like that ready to go, and to understand how they would work.

Finally, one of the things we should recognize at this point is that the planet is going to warm no matter what we do. So one of the things we have to study is how to adapt. Most of the temperate countries may not have to do a whole lot, but for many low-latitude countries adaptation is probably a much more important question that will require both private and public sector attention. So, adaptation is an area we had better look at very carefully.

SCOTT BARRETT:

The problem of climate change is unprecedented. And a fundamental challenge it raises for research is to think about what kind of institutional designs might get us from here to there—to be able to prevent environmental catastrophe, when market forces favor business as usual—in enough time.

NICHOLAS STERN:

My list for research topics fits quite closely with those that we've just heard. I'll be brief as I outlined some key areas of research in this morning's presentation.

I would add—and it would be my first thing—that we need to think carefully about the ethics of climate change and responses to it. Much of policymaking in this area derives inevitably from approaches to what's right and what's responsible. And I think we ought to think about and discuss that directly and rigorously. We can think through, as Tjalling Koopmans argued, the consequences of different kinds of assumptions on the ethics and come to understand the ethics that way. It's a kind of thought-experiment approach to moral philosophy, which is quite fundamental, I think.

Second, I would look at the theory and practice of extreme events. The kind of work that Marty Weitzman has been doing is very instructive. I think there's a theory of ambiguity, a theory of uncertainty, a theory of genuine lack of knowledge about probabilities, that is just developing among mathematicians, where you relax the von Neumann-Morgenstern assumptions a bit and you lose some of the thrust and results of expected-utility theory, but you're still left with something. A lot of our problem arises from not knowing what the probability distributions are, which makes it a bit presumptuous even to attach Bayesian priors to them. So I think that kind of theoretical research is important. So is empirical work to try to understand how societies cope, or do not cope, with the kinds of stress that could arise, and thus what kind of migration or conflicts might follow. For example, what we're seeing now in Darfur is partly the result of climate change, where 'mobile' pastoralists after long periods of drought are running into 'fixed' agriculturists.

Third, I think there's a lot to be learnt in the theory and practice of technological inducement. I would agree with Jeff Sachs on the importance of regulation on that front, as making things move quickly, but we'd have to think hard about whether going that route leads to efficiency losses.

Fourth, I would also be very happy to see pilot projects and much more research on deforestation. I suspect that the costs of deforestation will look quite small in some parts of the world and quite large in others, and there's a research issue to try to identify where they may be low and where they might be high.

Last, I think that studies on international action as proposed by Scott Barrett would be tremendous. International action is a very important part of what's needed. How we design, for example, international cap-and-trade schemes, how we give the kind of confidence that's required by setting targets for 2020 and 2050, for example, and how those targets would or could actually develop into treaties where appropriate, I think, are important subjects for research.

Chapter 13: Final Comments

WILLIAM NORDHAUS:

I very much enjoyed the comments. I learned a lot, as I always do, from this very talented group of people. And as far as Jeff Sachs is concerned, one of the things I've learned over the years, following him through wage and price rigidity, Russian reform, hyperinflation, development, debt crises, and now the earth, is that he's almost always right. The other thing I've learned is that Jeff engages in what you might call aspirational economics, and so, while I might not agree with all of his redefinitions and recalibrations, I think his are reasonable goals. We've been interchanging on this now for a couple of months, and I've learned a lot.

WILLIAM CLINE:

First let me take up a statement that Jeff Sachs made. I think he essentially said that there's really not that much difference among estimates of the carbon tax. I think there's quite an extreme difference. The Stern Review, my analysis, and Jeff's own diagnosis all come up with about the same number for what the carbon tax should look like in the fairly near future, and that's $25 to $30 per ton of carbon dioxide, which is about $100 to $120 per ton of carbon. While Bill Nordhaus and Rob Mendelsohn may have raised their estimates, the last time I looked, their optimal carbon taxes were much lower. Bill had $20, which is a lot lower than $120. And Rob had an even lower figure, I think, of $1.1 rising to $10 over 50 years or so. So, there is a difference. I don't think that difference should be lost sight of, and I think it's important to reach a view on what's the right way to go.

Second, as regards the Stern Review, I continue to be uneasy that more than 95% of the damage-avoidance benefits are not felt until after 2200. I guess by implication Nick is comfortable with this?

SCOTT BARRETT:

I don't think the biggest issue is deciding *what* we should do about the climate change problem. I think the bigger challenge for the world is, once we've decided what we want to do, *how* do we do it. I think this challenge is greater than any the world has faced before. Because the need is to transform technology worldwide when the market wouldn't want to do this on its own.

I think those global institutions that were established after World War II have really been neglected. If you don't use them and you don't believe in them they start to fall apart. But I draw hope from an agreement on protecting the oceans from oil pollution, whose first negotiations began in the 1920s. The first such agreement was actually reached in the 1950s, 30 years later. That agreement never entered into force because no one could see how it could be made to work. Then a new agreement was negotiated in 1973. That also was not going to enter into force until finally, in 1978, a totally different approach was tried, which began with a unilateral policy by Jimmy Carter. That approach has worked extremely well, and the agreement has been revised over and over again, most recently to require double hulls for oil tankers.

So, when I think about climate, I would share Jeff Sachs's ultimate optimism.

JEFFREY SACHS:

I think we all agree that there are two big issues for policy design.

One is R&D, because climate change is intrinsically an issue about technological change—not only about technology adoption, but introducing new technologies. And we know that that is a very rich institutional environment because of the public-goods nature of knowledge. Remarkably little real effort is being made right now to design decarbonized energy systems. In the US, every recent State of the Union address has paid lip service to the need but the actual level of effort is tiny. So, there needs to be a significant scaling up of research and development funding. And how to do that effectively is a very practical issue where both theory and the nitty-gritty details are helpful.

The second issue for policy design is that cap-and-trade is the dominant mechanism for getting a price of carbon into the market. This issue is raised by the Stern Review, but I have reservations about what seems to be the great momentum that cap-and-trade has acquired. I worry that cap-and-trade gives no signals for the future that are at all adequate, and I'd much rather have a tax and a price that's set for many years to come. What's interesting about the carbon price is what it's going to be in 15 and 20 years' time, not what it is today. The carbon price has a big impact on the kind of power plants that get built. In the United States, it gets incorporated into the prospectuses that go to the state regulatory agencies for the utilities, for example. The utilities have to justify why they're going to invest in an IGCC plant that captures carbon versus not, and that justification has to do with the prices they expect to face. They're going to argue that today's price on cap-and-trade is the one they're going to use to differentiate a carbon-capture plant from one that's not. But that won't work. We need longer-term signals, and I don't think we've done a very good job of thinking about that.

We have three kinds of instruments for influencing emissions. Two of them are similar: taxes and cap-and-trade. We know that under certain conditions these are the same and under other conditions they're related. The third is standards. Economists don't like standards, but I think standards are going to play a very important role here. How much carbon is emitted—say how many tons of carbon per quad of energy produced in a power plant—is going to be the kind of standard that will be adopted, just as we have fuel efficiency standards for automobiles. What are the cement, the steel, the power industry going to do in terms of industry standards? It's pretty clear that this is a part of policy design that we need to think much more about.

A further policy issue is that the whole damage and adaptation side is miserably underrepresented. Mitigation is fun, clean, and not so site-specific (except that, say, in windy places you can put up wind turbines and in sunny places you might do concentrated solar power). But adaptation is very, very site-specific. It's deeply ecologically based. It depends on characteristics of local hydrology, precipitation, topography, and 100 other very basic things: crop type, climate system, and so forth. It's very complicated and nobody has really done very much about it. We don't have good practice in climate management, even in responding to climate variability, El Niño variability—even things where there is a known signal. Poor countries in the line of fire just wait. They do very little adaptation to begin with. El Niño hits, and then they have floods and disasters. At least in my experience there are hugely nonlinear social effects from such events, just as there are hugely nonlinear ecological effects. Societies may collapse when climate change goes above a certain point. You get a bad harvest, the banking system fails, the government falls, and you end up getting a huge multiplier in the social consequences from what looks like a moderate ecological or hazard shock.

Part of the reason why nobody has really gotten started on adaptation is that until very recently we have had too little detailed climate knowledge to allow us to make downscaled projections. There are certain things we could do on adaptation even without downscaled climate models; for example, we already know that the Himalayan snow melt is going to cause huge changes in water supply on the Indian subcontinent. But a great deal more needs to be done.

I would also make two interconnected practical points, which are my favorites and not always so well received. One is that intrinsically this is a cross-disciplinary topic and the work absolutely should proceed in cross-disciplinary teams, and universities should support all of us to be able to do that better. Mechanisms ought to be created so that engineers and climatologists and economists and public-health specialists don't just talk to each other at meetings, but actually constitute teams for targeted output.

The other practical point is that practice and theory are inextricably linked in this case. This is, again, sometimes a minority opinion within universities, but I would advise faculty and students to get out there and advise a government on its actual negotiations in COP 13 (the Conference of the Parties of the UN Framework Convention on Climate Change). Take on a real challenge, learn how incredibly tricky it is, be told, "yeah, we know the theory stuff, but here's our real problem….", and start getting deeply into the nitty-gritty of it. And doing this will also open up a whole theoretical world that I believe we often miss.

So, I think that on the climate change issue, theory has been hugely important, and what Bill Nordhaus started us on quite a long time ago remains essentially how we think about the issue today. But at this point it's really the facts that count. It's the detailed knowledge that we ought to be discussing, not the overall framework.

ERNESTO ZEDILLO:

Thank you. We have a time restriction, and I had to take a decision between allowing audience members to speak and ask questions or to listen, as we have, to our panelists. And, as you see, I opted for the second. So I will just ask for a final comment, and then proceed to close the meeting.

NICHOLAS STERN:

Thank you all very much. That's the most important comment. I've learned a lot today, and I've enjoyed today, and I've enjoyed the interactions with members of the panel over these last months and years, so thank you. Thank you, Ernesto and Haynie and everybody who put all this together.

Bill Cline raised a question on the weight in the far end in our calculations in the Review—that is, the finding that most of the damage avoidance benefits are not felt until after 2200. My suggestion would be to raise the value of η (the elasticity of marginal utility) a bit. If η goes up from one to two, then the proportion of damage-avoidance benefits that comes from the far end falls to about 11 percent. Bill, you and I seem to be settling on η equals 1.5 or thereabouts. I'll be with you on that. And that calculation still yields the result that the damages are much bigger than the cost of action.

Finally, I'll tell you what I'm going to do. I'm going to work on the kinds of problems a number of people raised on adaptation and the importance of looking at adaptation in a particular place, and, similarly, the problems of moving to a low-carbon technology in a particular place. And the particular place I'm going to work on is India because that's where I enjoy being, and that's a country that is vital to this whole story. Thank you.

Chapter 14: Concluding Remarks

Ernesto Zedillo

Let me just finish by expressing that I would like to be as optimistic as Jeff Sachs about the engineers and the politicians. Maybe I could be as optimistic about the engineers, but I am afraid I have good personal reasons not to be as optimistic about what politicians will do in the future about this problem. Jeff is betting that in three years' time we will have a post-Kyoto agreement that will contain a clear target for carbon emissions. Maybe we will have such an agreement but I'm not so sure that we will have the mechanisms to make it really enforceable. We may end up again with something full of hot air and no real commitments. And, you know, dear Jeff, that that has happened not only in this field but in various others you have been following closely, including official development assistance.

You seem to believe that a miracle is going to happen in the next US presidential election and that the world will start to change for the better. But the international political economy of this issue is extremely complicated. I think Scott Barrett is right when he says that among the global challenges, among the global public goods that are vulnerable in the 21st Century, climate probably is the most difficult to tackle.

I'm not saying that climate change is the most important problem we have as humanity. I happen to believe that nuclear proliferation is a much more serious and threatening problem than climate change, and also that poverty in many regions of the world could be a more explosive problem than climate change. But I agree with Scott that among the international challenges we face, this is extremely complicated from a political perspective, and I simply don't see the political leadership starting to seriously address this question.

I don't know who is right, Nick Stern or the ramp-up or ramp-in guys, and I personally would settle for the most modest targets, or the lower carbon tax. But even to implement that, I think, is going to be very tough. So, let's see who is right. I think the real proof is going to be in the carbon tax or the caps that are actually adopted, if there is such a thing as a post-Kyoto agreement.

What can we do meanwhile? I think we need the research community to continue working on this and to react as our friends here on the panel have reacted with great responsibility. I know that they have invested many days reading Nick Stern's report, doing further work with their own models, and now we are trying to entice the research community to get more involved in these questions. Maybe that's the only thing we can do, and be hopeful that the political community not only pays more attention but gets hands-on into doing something about this and the other huge global challenges that we face.

What I really want to do at the end is to thank profoundly Nick Stern for having made this trip to the United States and to congratulate him and his team for the wonderful work that they have done.

I should also recognize the British government for this initiative. Now I am waiting for the British government to put their money where their mouth is, and that will be terrific. I think that will be the kind of leadership that is needed.

Of course, I want to wish Nick a successful renewal of his academic career. We'll hope to see him back soon now in his new capacity as professor at the London School of Economics. And, of course, I want to thank our wonderful panel for their contributions, and I want to thank you all for having been here today.