Debating Climate Economics: The Stern Review vs. Its Critics

Report to Friends of the Earth-UK
Frank Ackerman[1]
July 2007

Background

In 2005, British Chancellor Gordon Brown asked Sir Nicholas Stern to conduct a major review of the economics of climate change, as a guide to developing government policy. Stern is a well-respected, established economist: he has been the chief economist at the World Bank, the second permanent secretary of HM Treasury, and the head of the (UK) Government Economic Service. It is not a background that suggested he would make radical new departures in his latest report.

Yet the Stern Review,[2] released in late 2006, expressed alarm at the impending climate damages that will result from business as usual, and presented novel economic arguments endorsing prompt and vigorous action. Other economists were quick to respond, in many cases quite critically. How could Stern have strayed so far from the majority of economic analyses, which tend to recommend much smaller and slower responses? Stern was accused of numerous violations of standard economic methodology, which supposedly led to his "errors."

This report reviews and explains the differences between Stern and his academic critics. While the Stern Review is not a perfect document, it rests on much sounder ground than the economists who have attacked it. The Stern Review illustrates important ways in which economic analysis can be made to reflect the urgency of the climate problem. And it raises crucial questions about the economic aspects of climate change – even though it ultimately fails to find successful solutions to some of the important problems.

What did Stern conclude?

"The scientific evidence is now overwhelming: climate change presents very serious global risks, and it demands an urgent global response…The benefits of strong, early action considerably outweigh the costs."[3] This central conclusion from the Stern Review will not come as a surprise to scientists who study climate change. Nor will it startle those who are troubled by the early signs of global warming, including the intensification of extreme and variable weather conditions. But in the world of academic economics, it is so unusual that it requires detailed justification.

---

[1] Global Development and Environment Institute, Tufts University, Medford MA 02155, USA. Thanks to Simon Bullock and Elizabeth Stanton for helpful comments on an earlier draft.
[2] The Stern Review is available on-line, with background and other related documents, at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm
[3] Stern Review, long executive summary, pp.1-2.

Stern found that under business as usual (i.e., assuming no new policies to reduce carbon emissions), the concentration of greenhouse gases in the atmosphere could reach double the pre-industrial level as early as 2035. This would essentially commit the world to more than 2^oC of warming. By the end of the century, business as usual would lead to more than a 50% chance of exceeding 5^oC of warming, implying disastrous changes in natural ecosystems and human living conditions around the world.

Stern describes the impacts of unchecked warming in both qualitative and quantitative terms; the qualitative images are perhaps more sweeping and powerful. For example, human actions create "risks of major disruption to economic and social activity, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century."[4] American readers should remember that this was written in a country where World Wars I and II loomed considerably larger than in the US.[5] An average global warming of 5^o (all temperatures cited here are in degrees Celsius) would cause "a radical change in the physical geography of the world [that] must lead to major changes in the human geography – where people live and how they live their lives."[6] The qualitative descriptions of climate impacts are discussed in the final section, below. Most of the economic debate, however, concerns Stern's quantitative estimates.

The economic model used in the Stern Review finds that the damages from business as usual would be expected to reduce GDP by 5% based on market impacts alone, or 11% including a rough estimate for the value of health and environmental effects that do not have market prices ("externalities," in the jargon of economics). If the sensitivity of climate to CO_2 levels turns out to be higher than the baseline estimates, these losses could rise to 7% and more than 14%, respectively. A disaggregated description of impacts by sector and region is generally in agreement with these numbers, according to the Review. Stern speculates that an adjustment for equity weighting, reflecting the fact that the impacts will fall most heavily on poor countries, could lead to losses valued at 20% of global GDP. These figures are substantially greater than the comparable estimates from most economists.

These damages can be largely avoided, at much lower cost, through emissions reduction (or "mitigation," in the jargon of climate change). Stabilization at 500–550 parts per million (ppm) of CO_2-equivalent[7] in the atmosphere would avoid most, though not all, of the "business as usual" damages. Both direct estimates of mitigation costs and a review of results from many different models suggest that stabilization at this level would cost about 1% of GDP. Stabilization below 450 ppm, according to Stern, is no longer feasible

[4] Stern Review, short executive summary, p.1.
[5] Unlike the US, the UK experienced heavy bombing during World War II. UK deaths, as a percent of population, were 3 times the US level in World War II, and 20 times the US level in World War I. (Wikipedia entries on "World War I casualties" and "World War II casualties.")
[6] Stern Review, short executive summary, p.1.
[7] These Stern calculations of CO_2-equivalent emissions include about 50 ppm contribution from non-CO_2 greenhouse gases; thus this range is comparable to 450–500 ppm of CO_2 alone.

in view of the large amount of carbon already in the atmosphere; he suggests the relevant range of targets is now 450-550 ppm of CO_2-equivalent.[8]

Later chapters of the Review make many interesting and insightful comments about national policy options and the role of international agreements. However, the principal controversies have concerned the economic analysis described above, with its conclusion that for an immediate and vigorous mitigation effort, the benefits (avoided damages) far exceed the costs. This report reviews the controversies around the Stern Review, concluding, in brief, that there is more support for Stern's analysis than for his conservative critics. Indeed, criticism could more accurately be pointed in the opposite direction: if anything, Stern understates the urgency of the climate problem, and misses some of the strongest arguments for immediate action.

Criticisms of the Stern Review

The extensive criticisms of the Stern Review's economics raise three principal points:

- the discount rate is said to be too low;
- the treatment of risk and uncertainty is inappropriate; and
- the calculation and comparison of costs and benefits is done incorrectly.

In the opinion of a number of economists who have discussed the Stern Review, these criticisms invalidate Stern's conclusion that the costs of climate mitigation are much smaller than the benefits.

1. Is the Stern discount rate too low?

For economists, calculation of future costs and benefits routinely involves a discount rate. The logic of discounting starts from the fact that money today is worth more than the same amount of money next year, or farther into the future (even if there is no inflation). No financial institution makes zero-interest loans, in which you pay back, in the future, exactly what you borrowed in the past. If you could borrow money at a 3% interest rate, getting £100 today would cost you £103 a year from now. To express current and future costs and benefits on a comparable basis, economists *discount* future amounts, converting them to the equivalent *present value*. At a 3% discount rate, £103 a year from now has a present value of £100.

Because the climate impacts of today's decisions span such long periods of time, the choice of a discount rate is one of the most important factors in the economic analysis of climate change. Stern's preferred discount rate, 1.4% (explained below), is much lower than the rates used in traditional climate economic models. For **William Nordhaus**, "the *Review*'s radical revision arises because of an extreme assumption about discounting…this magnifies enormously impacts in the distant future and rationalizes

[8] This is comparable to 400-500 ppm of CO_2 alone (see previous note). The rationale for this target range is spelled out in Chapter 13 of the Review, and discussed below.

deep cuts in emissions, and indeed in all consumption, today."[9] As Nordhaus suggests, a lower discount rate makes the far future look more important today, and supports greater future-oriented investment.

In selecting the appropriate discount rate for long-term public policy decisions, economic theory often distinguishes between two components. The *rate of pure time preference* is the discount rate that would apply if all present and future generations had equal resources and opportunities. (As discussed below, the rate of pure time preference might or might not be zero; a zero value treats the welfare of all generations as equally important.) In addition, there is a *wealth-based component* of the discount rate, reflecting the assumption that if future generations will be richer than we are, then there is less need for us to invest today in order to help them protect themselves. In the notation of the Stern Review, the discount rate, r, is the sum of these two parts:

(1) $$r = \delta + \eta g$$

Here δ (delta) is the rate of pure time preference, and g is the growth rate of per capita consumption. If per capita consumption is constant, implying that $g = 0$, then the discount rate $r = \delta$. The second parameter, η (eta), determines how strongly economic growth affects the discount rate. A larger value of η implies a larger discount rate, and hence less need to provide today for future generations (as long as per capita consumption is growing).

Nordhaus' critique centers on Stern's value for δ, the discount rate that would apply if all generations were equally well off. Stern reviews and endorses the philosophical arguments for viewing all generations as people of equal worth, deserving equal rights and living conditions.[10] These arguments are often taken to imply that pure time preference should be zero. However, many economists believe that people reveal their time preferences through choices about savings and other actions affecting the future, and deduce from this that the rate of pure time preference must be greater than zero. (If every generation was equally important to people today, the economists object, wouldn't we all be saving a lot more – perhaps most of our incomes – for the future?) In addition, pure time preference precisely equal to zero causes technical problems in some economic theories.[11]

Stern just barely avoids setting pure time preference equal to zero. While generally accepting the philosophical arguments for treating all generations equally, he also observes that there is a small, but non-zero, probability that future generations will not exist – for example, if a natural or man-made disaster destroys most or all of the human race. The probability of destruction of humanity is, arbitrarily, assumed to be 0.1% per year; pure time preference is therefore set equal to 0.1%. That is, Stern suggests that we

[9] William Nordhaus, "The *Stern Review* on the Economics of Climate Change," November 17, 2006, p.6. Available at http://nordhaus.econ.yale.edu/SternReviewD2.pdf .
[10] Stern Review, Chapter 2 and its appendix.
[11] With zero pure time preference, models of economic growth behave illogically when extended to an infinite time horizon. It is not clear whether this is a fatal flaw in an analysis limited to a few centuries.

are only 99.9% sure that humanity will still be here next year, so we should consider the well-being of people next year to be, on average, 99.9% as important as people today.

To calculate the discount rate using equation (1), Stern estimates that the growth of per capita income will average 1.3% per year, and sets $\eta = 1$. Thus his discount rate is

(Stern) $$r = \delta + \eta g = 0.1\% + (1 * 1.3\%) = 1.4\%$$

In contrast, the UK Treasury's Green Book, providing the government's current guidance for policy appraisal, discusses catastrophic risk and other grounds for pure time preference, recommending $\delta = 1.5\%$. (While employing the same logical framework, it uses different notation and terminology, and offers almost no explanation of its numerical estimates.[12]) Like Stern, the Green Book assumes $\eta = 1$; it estimates the long-term growth rate of per capita income, g, at 2%, implying

(Green Book) $$r = \delta + \eta g = 1.5\% + (1 * 2.0\%) = 3.5\%$$

The Green Book also calls for a gradual decline in discount rates over the very long run, dropping in several stages to 2.5% after 75 years and 1.0% after 300 years. However, such a decline may be less significant than it looks; the first few decades of discounting at higher rates are the most important in terms of evaluation of future costs and benefits.[13]

Nordhaus interjects another idea from economic theory: in an abstractly perfect market economy, the discount rate should match market interest rates, or rates of return on capital. In a textbook world of perfect markets and perfect rationality, where everyone is well-informed and has access to capital markets, and everyone thinks about short-term investments and long-term policies in a consistent manner, the discount rate would be equal to the interest rate, since both would express individuals' preferred trade-off between current and future incomes. Ignoring the reasons why this bit of theory might not apply in the real world, Nordhaus maintains that the discount rate should initially match an interest rate of about 5% above inflation. (This discussion uses "real," or inflation-adjusted, quantities throughout.) To achieve this goal he argues that pure time preference, δ, should, at least initially, be as high as 3%.[14]

To confirm the significance of this technical debate, Nordhaus runs his own DICE model with Stern's 1.4% discount rate, and again with Nordhaus' preferred, much higher rate.

---

[12] The calculation of the discount rate is explained in Annex 6 of the Green Book, at http://greenbook.treasury.gov.uk/annex06.htm . In the Green Book, the symbol δ and the term "pure time preference" both exclude catastrophic risk, while in the Stern Review and this report, the same symbol and term include catastrophic risk. The Green Book's ρ corresponds to Stern's δ; likewise, the Green Book's μ corresponds to Stern's η.

[13] This point is explained in greater detail in Frank Ackerman and Ian Finlayson, "The Economics of Inaction on Climate Change: A Sensitivity Analysis," *Climate Policy* vol. 6 no. 5 (2006), pp.509-526.

[14] Nordhaus uses different notation, and refers to the rate of pure time preference as the "social discount rate." (This report uses the Stern notation and terminology throughout.) In subsequent work Nordhaus has decreased δ and increased η, suggesting that these offsetting adjustments are needed to keep the discount rate consistent with interest rates.

The results can be compared by looking at the "social cost of carbon," or "optimal carbon tax," a measure of the incremental benefits of reducing carbon emissions. The social cost of carbon starts out at under $20 per ton of carbon with the Nordhaus discount rate, vs. $159 when Nordhaus uses the Stern discount rate. The latter number is still only about half of the Stern Review's own estimate of $311 per ton, suggesting that factors other than the discount rate (and/or differences between DICE and the Stern Review's PAGE model) also play a role.

Partha Dasgupta presents a complementary critique of Stern, addressing a different aspect of the discount rate.[15] Focusing on the ethical implications of discounting, he interprets δ as the measure of the trade-off between present and future, independent of wealth differences, and η as the measure of the trade-off between rich and poor, independent of time differences. In this framework,

- $\eta = 0$ implies that ***every pound is of equal value*** regardless of who receives it;
- $\eta = 1$ implies that ***every 1% increase in a person's income is of equal value*** regardless of the wealth of the person who receives it; and
- $\eta > 1$ implies that ***a 1% increase in income is of greater value*** to a poorer person.

Dasgupta endorses Stern's argument that δ is close to zero, but maintains that equity requires much more concern for the poor, reflected in a larger η; Dasgupta suggests a range of 2 to 4. If per capita incomes are expected to continue growing in spite of climate change, as most economists (including Stern) assume, then using a larger η in equation (1) leads to a higher discount rate, and indirectly to less investment in the future.

How can a concern for equity lead to doing less for future generations? The source of the paradox is the economists' assumption that future generations will be better off than we are; in this story, it is assumed that we are the poor, and those who come after us are the rich. If that were true, then as modern Robin Hoods, we could strike a blow for equality by taking money from our children's inheritance and spending it on ourselves today. On the other hand, if climate change or other problems will make future generations worse off, the argument reverses itself: in that case, the present generation should do much more for its poorer descendants. If the lives of future generations will be sufficiently worse than ours, the discount rate could even become negative, implying that £100 of benefits in the future would be worth more than £100 today. Dasgupta has raised this possibility in other writings on the subject.

Of course, not everyone is equally wealthy within any generation; Dasgupta's strong views on equity would also call for substantial redistribution within the present generation. Indeed, Dasgupta hints that Stern's $\eta=1$ (as opposed to $\eta=2$ or more) reflects an insufficient concern for the problems of poverty today – as well as an excessive concern for the well-being of the allegedly more affluent generations to come.

[15] Partha Dasgupta, "Comments on the Stern Review's Economics of Climate Change," revised December 12, 2006, http://www.econ.cam.ac.uk/faculty/dasgupta/STERN.pdf .

Dasgupta also objects that Stern's low discount rate and heightened concern for future generations should imply an implausibly high savings rate, far higher than observed rates of saving. If you cared that much about the future in general, and if you made all your economic decisions on a consistent, theoretically sound basis, you would be saving a huge proportion of your income for your descendants. In a short, technical response specifically to this point, **Brad DeLong** argues that the implausible savings rate results from the additional assumption that there is no technological progress; in a world with technical change, Stern's discount rate implies entirely believable savings rates.[16]

In a forthcoming review of the Stern Review, **Martin Weitzman** suggests that differing discount rates can account for the entire disagreement between Stern and his critics.[17] Weitzman proposes, in terms of equation (1), his guess at the consensus estimates among economists studying climate change: $\delta = 2\%$, $\eta = 2$, $g = 2\%$. The result is a discount rate of $r = 2\% + 2 * 2\% = 6\%$. For events 100 years from now, the present value of future damages is 100 times greater at Stern's 1.4% discount rate than at Weitzman's "consensus" 6% discount rate. According to Weitzman, this gap is sufficient to make Stern's proposal for spending 1% of GDP on mitigation obviously attractive at Stern's discount rate, and, equally obviously, unattractive at the "consensus" rate. The notion that discount rates should in theory match current interest rates is a surprisingly complex question, requiring a prior determination of which interest rate to use. Weitzman himself, drawing on his work on the economics of uncertainty, favors a discount rate that declines sharply over time, approaching the Stern level as time goes on. While criticizing several aspects of Stern's presentation of the issue, Weitzman ultimately concludes that "Stern may be right for the wrong reasons," as explained below in the discussion of risk and uncertainty.

A somewhat different evaluation of the role of discount rates is presented in a brief comment on the Stern Review by **Kenneth Arrow**, one of the leading figures in twentieth century economic theory.[18] (Arrow takes it for granted that policy to limit carbon emissions is crucial; he reports first learning of the problem while taking a meteorology class in 1942, in which the professor mentioned, as a casual illustration of the principles of atmospheric science, that the growing rate of fossil fuel combustion was going to make the earth warmer in the future.) Arrow accepts the cost and benefit calculations of the Stern Review, but not its discount rate. Using Stern's high climate sensitivity scenario and $\eta = 2$, Arrow finds that the benefits of Stern's proposals for climate mitigation exceed the costs as long as the rate of pure time preference is less than 8.5%. As he notes, no one has proposed a rate of pure time preference nearly as large as 8.5%; thus Arrow concludes that Stern's cost-benefit argument for active climate policy is still valid at the discount rates conventionally favored by economists.

---

[16] Brad DeLong, "Partha Dasgupta Makes a Mistake in His Critique of the Stern Review," a blog entry for November 30, 2006, http://delong.typepad.com/sdj/2006/11/index.html . Discussion between Dasgupta and DeLong continues on December 7, at http://delong.typepad.com/sdj/2006/12/brad_delongs_se.html

[17] Martin Weitzman, "The Stern Review of the Economics of Climate Change," forthcoming in *Journal of Economic Literature*, http://www.economics.harvard.edu/faculty/Weitzman/papers/JELSternReport.pdf .

[18] Kenneth J. Arrow, "Global Climate Change: A Challenge to Policy," *Economists' Voice*, June 2007, www.bepress.com/ev .

Stern's responses to criticisms on the discount rate[19] reiterate the ethical arguments for pure time preference (δ) being close to zero. At δ = 1.5%, he suggests, you are telling your grandchildren that their lives and incomes are only half as important as your own, simply because they live 50 years after you. Stern is more willing to consider changes in η, though not to the extent that Dasgupta proposes. (If Dasgupta's proposed values for η were appropriate, Stern observes, very radical redistribution within the present generation, from rich to poor, should be high on the political agenda.)

Sensitivity analyses by the Stern team show that with either δ = 1.5% or η = 2, much though not all of the present value of climate damages would be eliminated; however, the remaining damages would still exceed the costs of mitigation. (See Table 1; additional items in the Table are discussed in the next section.)

Table 1: Total cost of climate damages – sensitivity analyses

	Change in global per capita consumption (percentage points) *
Stern Review base case Baseline climate sensitivity, includes catastrophes and non-market impacts, uncertainty (Monte Carlo) effects, pure time preference (δ) = 0.1%, η = 1	**-10.9**
Using all base case assumptions except:	
Pure time preference = 1.5%	-3.3
η = 2	-3.4
All uncertain parameters fixed at best guess (modal) values	-3.3
Damage function exponent (γ) = 3	-34.2
High climate sensitivity	-14.5
Eliminate risk of catastrophes	-8.0

* - percentage loss of global per capita consumption compared to a scenario with no climate damages, measured on a "balanced growth equivalent" basis – see Stern Review for detailed definitions.

Source: Calculated from appendix to Stern Review postscript; Simon Dietz et al., "Reflections on the Stern Review," *World Economics* 8 no. 1, Table 1; and personal communication from Simon Dietz.

[19] See the Stern Review's postscript, appendix to the postscript, and other recent writings on the Stern Review website.

2. How do risk and uncertainty affect climate economics?

The second major innovation in the Stern analysis is the treatment of risk and uncertainty connected to climate change.[20] Although the broad outlines and major findings of climate science are increasingly definite, many crucial details remain uncertain, and may not be known until it is too late to do anything about the problem. Both the expected severity of climate impacts and the probability of an abrupt catastrophe are strongly connected to temperature increases, which in turn are strongly connected to atmospheric concentrations of greenhouse gases. However, the precise strength and timing of these relationships remain uncertain. Some of the uncertainty can be addressed by further research, but some may reflect the inherent unpredictability of nonlinear systems such as the earth's atmosphere – the problem that motivates the fields of chaos theory and complexity theory.

Stern introduces issues of uncertainty into the economic calculations in three ways.[21] The first involves the sensitivity of climate to greenhouse gas concentrations. The baseline scenario follows the IPCC's Third Assessment Report (2001) in assuming that a doubling of pre-industrial CO_2 concentrations would lead to warming of $1.5^o – 4.5^o$. Some newer research suggests that climate feedback mechanisms may increase sensitivity beyond that level. Accordingly, Stern's high climate sensitivity scenario assumes that the same doubling of atmospheric CO_2 would lead to $2.4^o – 5.4^o$.

Second, the PAGE model, used in the Stern Review, includes an estimate for the risk of an abrupt climate catastrophe. The model assumes that once a threshold temperature is reached (the threshold itself is uncertain, but averages 5^o above pre-industrial temperatures) the probability of catastrophe increases by 10% for every additional degree C of warming; the catastrophe has a value of 5-20% of output.[22] As Stern notes, this is similar to the treatment of catastrophe in Nordhaus' DICE model. Most other economic models, however, do not include estimates for catastrophic events.

Finally, PAGE is designed to reflect risks throughout its calculations, through a statistical technique known as Monte Carlo analysis. For 31 key parameters, PAGE assumes that there is a range of possible values. For each of these parameters, the model randomly selects a value from the range of possibilities, each time it is run. The model is run repeatedly – 1000 times, in this case – and the weighted average of the results is used as the model's estimate.[23]

---

[20] Formally, risk is often taken to mean events where different outcomes have known probabilities, in contrast to uncertainty, where the probabilities are unknown. However, this distinction is often blurred in informal discussion, such as the text of this section.

[21] See the summary in one of the Stern team's responses to critics: Simon Dietz, Chris Hope, Nicholas Stern and Dimitri Zenghelis, "Reflections on the Stern Review (1): A Robust Case for Strong Action to Reduce the Risks of Climate Change," *World Economics* vol. 8 no. 1 (January-March 2007), pp. 121-168.

[22] Stern Review, p.153.

[23] The results are weighted by "utility," or consumer satisfaction, which Stern assumes is equal the logarithm of consumption. (This is a common, but far from universal, assumption in economic analyses.) Compared to an unweighted average, this procedure gives greater weight to model runs where climate damages are greater and incomes are lower.

For example, one of the most important parameters governs the relationship between temperature and (non-catastrophic) economic damages. A simple way for an aggregate economic model to estimate climate damages is to use the equation

(2) $$D = kT^{\gamma}$$

Here D is damage (either as a monetary amount, or as a fraction of output), T is temperature above pre-industrial levels, or above a base year such as 1990, and γ (gamma) is the exponent on temperature. Catastrophic damages are handled separately; equation (2) is a model of expected climate damages, excluding abrupt catastrophes. There is no experiment that determines the correct value of γ; it is an assumed, not an observed, value. Yet, as we will see, assumptions about γ are of critical importance. (More broadly, the form of equation (2) itself is an important simplifying assumption, but is not subject to empirical testing – except in retrospect, when it will be much too late.)

A common assumption, used in DICE and elsewhere, is that equation (2) is valid, and that $\gamma = 2$: i.e., damages are proportional to the square of the temperature increase. PAGE makes a similar assumption, but with more uncertainty about the exponent: it allows γ to be anywhere from 1 to 3, with 1.3 as the most common value, and an average of 1.8. Thus most PAGE runs have a lower value of γ than DICE, but some PAGE runs have larger values of γ – and hence much larger damages at high temperatures.

Each of these three methods of modeling uncertainty has an important influence on the results. Sensitivity analyses by the Stern team, as shown in Table 1, show that the estimated cost of "business as usual" climate damages would be increased by 3.6 percentage points (i.e., 3.6% of global consumption) by the high climate sensitivity assumptions. Similarly, removal of the calculation of catastrophic risks would reduce estimated damages by 2.9 percentage points. Elimination of the Monte Carlo analysis, doing one run of PAGE using the most common value for each parameter (such as 1.3 for γ), would reduce damage estimates by 7.6 percentage points.[24] In short, Stern's treatment of uncertainty is comparable in importance to the discount rate in determining the outcome of the model.

Despite its quantitative importance and its methodological innovation, the Stern treatment of uncertainty has received relatively little attention from economists. In some cases, aspects of the Review that reflect its treatment of uncertainty are mistakenly attributed to other factors: Nordhaus comments on the escalation from damages averaging 5 percent of output, up to a 14 percent reduction in consumption, but then asserts that it is due to inappropriate discounting.[25] **Gary Yohe**, on the other hand, correctly describes some aspects of Stern's approach to uncertainty as a source of the high estimates of damages;

[24] Dietz et al., p.144.
[25] Nordhaus, pp. 11-12. In fact, 5 percent is the Stern damage estimate with baseline climate sensitivity, and without non-market impacts, while 14 percent is the high climate sensitivity estimate, with non-market impacts included. Both use the same method of discounting.

he does not directly express agreement or disagreement.[26] **David Maddison** mentions the Stern analysis of uncertainty approvingly, as correcting a deficiency in most studies; he does comment that the economic valuation of catastrophe, and the range of possible values for the uncertain parameters, are themselves quite uncertain, and beyond the scope of the published economics literature. He concludes that despite these limitations, constructing a model with multiple methods for incorporating uncertainty "is a perfectly legitimate endeavour not least because so little is currently known about the nature of such damages."[27]

In a brief comment specifically on Stern's treatment of catastrophic damages, **Paul Baer** argues that much greater catastrophic impacts should have been included, starting at lower temperatures.[28] Stern's target for climate stabilization, according to Baer, would entail significant risks of the complete melting of the Greenland ice sheet, an important, much-discussed example of a climate catastrophe. Based on the non-zero risk of catastrophic damages at lower temperatures, Baer speculates that the optimal target for CO_2 reduction and temperature stabilization should be lower than Stern's levels.

Weitzman argues at length that uncertainty is the key to the climate problem. He describes Stern as being "right for the wrong reason," because Stern places too much emphasis on a debatable cost-benefit analysis, but too little on the need for social insurance against low-probability, catastrophic events. Weitzman applies a framework developed in the analysis of financial markets, where standard theories fail to explain puzzling patterns of behavior. Those standard theories assume investors can learn, through repeated experience, the probability distribution of the full range of possible market outcomes. But when (as usual) market structures are changing over time, there is never enough experience that is relevant to the current structure. In particular, it is intrinsically impossible to learn much from experience about the probability and magnitude of the extreme tails of a changing distribution – such as the worst-case outcomes that could lead to very large losses. Investors appear to worry a great deal about those unpredictable worst-case outcomes, a fact that explains a number of otherwise puzzling financial market results.

The analogy to climate change, according to Weitzman, is that we should worry less about calibrating the most likely outcomes, and more about insurance against worst-case catastrophes. Thus the IPCC's Fourth Assessment Report (2007) offers six "equally sound" scenarios, with a mean temperature increase over the next century of 2.8^o – well within the range of the ongoing debate over the impacts of predictable and expected damages. (Stern follows one of the IPCC scenarios, namely A2, in projecting somewhat greater damages from a century of business as usual.) Much more important than the

---

[26] Gary Yohe, "Some Thoughts on the Damage Estimates Presented in the Stern Review—An Editorial," *Integrated Assessment Journal* vol. 6 no.3 (2006), pp.65-72.

[27] David Maddison, "Further Comments on the Stern Review," p.3. Available at http://www.economics.bham.ac.uk/maddison/Stern%20Comments.pdf .

[28] Paul Baer, "The Worth of an Ice-Sheet: A Critique of the Treatment of Catastrophic Impacts in the Stern Review," http://www.postnormaltimes.net/blog/archives/2006/12/the_worth_of_an_1.html , December 23, 2006.

mean prediction is the fact that, according to Weitzman, the same IPCC report can be read as implying a 2 percent probability of a temperature increase greater than 6^{o}: a point at which we "are located in the terra incognita of what any honest economic modeler would have to admit is a planet Earth reconfigured as science fiction… [where] mass species extinctions, radical alterations of natural environments, and other extreme outdoor consequences will have been triggered by a geologically-instantaneous temperature change that is significantly larger than what separates us now from past ice ages."[29] While monetary valuation of these events would be a daunting task, there is no doubt that the benefits of avoiding 6^{o} warming would be enormous.

When it comes to policy implications, Weitzman offers only scattered comments, which he refers to at one point as "highly-speculative examples." (p.24) But his theory suggests a profound reframing of the issue. When homeowners buy fire insurance, or when healthy young adults buy life insurance, they are spending money to insure against accidents that have annual probabilities of a few tenths of a percent. A 2 percent risk of disaster is, from some perspectives, enormous: the death rate for US soldiers in the Iraq war is less than 2 percent per year, and no one views their job as a safe one. If expenditures on fire insurance for homeowners and life insurance for young adults are worthwhile, then perhaps we should be talking about the cost, and value, of insurance against the 2 percent chance of a 6^{o} warming, which would truly be a climate catastrophe.

In view of the limited economic commentary on Stern's treatment of risk and uncertainty, there is little in the way of a response. One major response from the Stern team explains their approach to risk and uncertainty, and rebuts a technical claim that they have double-counted the risk of catastrophe in their use of estimates from Nordhaus' earlier work.[30]

3. How should climate damages and mitigation costs be estimated and compared?

In addition to criticisms of the discount rate and the treatment of uncertainty, economists have also criticized Stern's estimates of the expected damages from climate change, the costs of mitigating those damages, and the comparison of damages and mitigation costs. The comments in this area are more detailed and less philosophical than the debates over discounting and uncertainty.

When it comes to estimating climate damages, **Richard Tol and Gary Yohe** believe that Stern has exaggerated throughout: "The *Stern Review* consistently selects the most pessimistic study in the literature for water, agriculture, health, and insurance."[31] On the question of refugees who may be displaced by climate change, they maintain that Stern has relied on the work of "a known alarmist."

[29] Weitzman, p.18.
[30] Dietz et al.
[31] Richard S.J. Tol and Gary W. Yohe, "A Review of the *Stern Review*," *World Economics* vol 7 no. 4, October-December 2006, pp.233-250; quote from p.236.

Robert Mendelsohn adds the claim that Stern has overstated the effects, or the certainty, of extreme weather events, and has downplayed the likely extent of adaptation to a changing climate. In general, Mendelsohn believes the damages from the early stages of warming to be quite small: "…there are hardly any damages associated with a 2^{o}C increase in temperature."[32] The ever-imaginative **Bjorn Lomborg** reveals that Stern's damage estimates are inflated because "he assumes that we will continue to pump out carbon far into the 22nd century – a rather unlikely scenario given the falling cost of alternative fuels…"[33] Lomborg also echoes many of the other criticisms discussed here, and asserts that Stern must be wrong because Nordhaus is known to be right.

A massive, two-part response by a group of British academics, including some well-known climate skeptics, critiques both the science and the economics of the Stern Review. In the economic critique, **Ian Byatt et al.** emphasize the uncertainty of events more than 100 years in the future, and the importance of Stern's low discount rate in highlighting those far-future impacts.[34] They object that the Stern damage estimates are dominated by the effects of extreme weather, social and political instability, and "knock-on effects."[35] All of these, they feel, are less certain and more conjectural than the better researched, and much smaller, estimates of predictable climate damages that are recognized by "everybody else."

Many economists also believe that Stern has underestimated the costs of mitigation. Tol thinks that Stern relies too heavily on one group of models, while other models would estimate higher costs of emission abatement.[36] Tol and Yohe present technical criticism of Stern's background paper on abatement costs. Mendelsohn observes that carbon recapture (one of Stern's solutions) is not yet a proven technology; in addition, Mendelsohn views renewable energy as expensive and problematical, and thinks Stern is too optimistic about future technological change reducing abatement costs.

Byatt et al. believe that costs of alternative energy sources are normally underestimated in advance, as shown by the history of nuclear power. They object that Stern relies too heavily on too few sources (although noting that those include meta-analyses of many different studies). They also complain that Stern includes estimates of cost reduction via active revenue recycling (using carbon tax revenues to reduce other taxes), induced technological change, and reductions in other pollutants that result from the decreases in fossil fuel combustion (in climate jargon, the "co-benefits" of carbon reduction).

---

[32] Robert O. Mendelsohn, "A Critique of the Stern Report," *Regulation*, Winter 2006-2007, pp.42-46; quote from p.46.

[33] Bjorn Lomborg, "Stern Review: the dodgy numbers behind the latest warming scare," *Wall Street Journal*, November 2, 2006. Unlike other authors discussed here, Lomborg is not an economist; he is a political scientist who frequently raises economic critiques of climate mitigation and other environmental policies.

[34] Ian Byatt, Ian Castles, Indur M. Goklany, David Henderson, Nigel Lawson, Ross McKitrick, Julian Morris, Alan Peacock, Colin Robinson and Robert Skidelsky, "The Stern Review: A Dual Critique – Part II: Economic Aspects," *World Economics* vol. 7 no. 4, October-December 2006, pp.199-229.

[35] Note for American readers: "knock-on effects" means indirect, usually undesirable, side effects. The term originated in rugby, where it refers to accidentally knocking the ball forward while trying to pick it up.

[36] Richard S.J. Tol, "The Stern Review of the Economics of Climate Change: A Comment," November 2, 2006, p.3. Available at http://www.fnu.zmaw.de/fileadmin/fnu-files/reports/sternreview.pdf .

In addition, there are criticisms of the manner in which the Stern Review compares costs and benefits. Tol and Yohe, among others, point out that Stern's mitigation expenditures of 1% of GDP, holding atmospheric greenhouse gas concentrations to 550 ppm CO_2-equivalent, will not avoid all climate damages – and therefore should be compared to the damages it will avoid, not to total damages. Tol and Yohe also express surprise that although Stern's marginal damage cost estimate is three times the previous estimate from HM Treasury, Stern's target for stabilizing greenhouse gas emissions is unchanged from the earlier Treasury study. If damages are so much higher, why isn't the stabilization target lower?

On the other hand, Mendelsohn thinks that Stern should have explored the costs and benefits of higher stabilization targets, such as 650 or 750 ppm; with Mendelsohn's low estimates of damages, these targets might be the optimal ones to aim for. Byatt et al. worry about the inefficiency that would result if climate-related investments were evaluated using Stern's low discount rate, while ordinary investments were evaluated using higher discount rates. (This inefficiency would mean that "too much" was being invested in climate protection, relative to other industries.) Lomborg repeats his longstanding claim that public funds would be better spent addressing other priorities rather than climate change.

Stern and his colleagues have responded to all of these criticisms on their website and in an initial round of articles. The Stern Review damage estimate of 5% of GDP is based on the science in the IPCC's Third Assessment Report (2001), and does not include externality values for unpriced damages to human health and the environment. It is higher than other estimates due to the lower discount rate applied to future damages, the expanded treatment of uncertainty, and the enormous impact of the risk of 5°C or more warming within the 200-year time frame of the study. Many other studies focus on the important, but much smaller, damages expected from 2-3°C. The Stern scenario with higher climate sensitivity, which puts business as usual damages at 7% of GDP, attempts to incorporate newer developments in science since the 2001 IPCC report (see discussion of uncertainty, above). Stern emphasizes that the externality valuations, boosting damages to 11% of GDP, or 14% with higher climate sensitivity, are uncertain and should be treated with caution, as should the guess at an equity adjustment, raising the total as high as 20% of GDP. The postscript to the Stern Review offers an expanded set of sensitivity analyses in its appendix, identifying several key factors that influence the damage estimates.

The mitigation cost estimate of 1% of GDP, according to the Stern website responses, is supported both by aggregate modeling exercises, and by more detailed, disaggregated studies of costs of carbon-reducing technologies. As a relatively constant cost throughout this century, it does not depend on the choice of discount rates. It does not include estimates of the value of the co-benefits of CO_2 reduction. It assumes a flexible market economy and sensible policies; in contrast, studies that assume economic rigidity and inappropriate policies naturally produce higher cost estimates. Stabilization at 450 – 550 ppm CO_2-equivalent, Stern's target range, would eliminate more than 90% of the damages from business as usual; those damages are heavily influenced by the risks at high concentrations and temperatures. Stern rejects Lomborg's imagined tradeoff between climate mitigation and other spending priorities, and reminds Lomborg that if we delay, climate mitigation will become much more expensive, if not impossible.

Following the publication of two of the sharpest critiques of the Stern Review in *World Economics*, the next issue of that journal published a range of responses from different members of the Stern team. Essentially every specific critique made by Byatt et al., and by Tol and Yohe, is challenged as inaccurate by Stern and his colleagues. The Stern Review did not include knock-on effects, or socially contingent impacts, in its damage estimates. The technical claims about flaws in the Review's background papers are disputed by the authors of those papers. Tol is said to have apologized in public for one of his major criticisms, which he now agrees is inaccurate.

Toward an evaluation of the debate

The debate over the Stern Review has captured the attention of a wide range of economists, most of them critical of Stern's conclusions. How should we evaluate the first few months of debate, as described above? This section briefly reviews the three areas of criticism discussed above; the final section raises a fourth major point that has received too little attention to date.

On discounting, the choices of both δ and η affect the discount rate. The choice of pure time preference (δ) is an ethical question, involving the value placed on the intrinsic well-being of future generations, independent of income. Stern favors a much lower value than most (not all) other economists, but the choice is not a matter of technical analysis. Rather, as the Review puts it, "if you care little about future generations you will care little about climate change. As we have argued that is not a position which has much foundation in ethics…[It is a position] which many would find unacceptable."[37] To quantify an ethical perspective that respects and validates the future, it is essential to set pure time preference close to zero.

Regarding the choice of the second parameter, η, involving the value placed on changes in wealth, the arguments are less clear. Sensitivity analyses show that the exact Stern Review value of $\eta$is not crucial to the general conclusions, i.e. that the benefits of active, immediate mitigation outweigh the costs. (In this context, recall Arrow's conclusion that the benefits exceed the costs, even with $\eta = 2$ and a much higher rate of pure time preference.)

The argument that discount rates should match current interest rates is surely a mistake, grounded in abstract theories of perfect markets, not in reality. Markets are imperfect in countless ways; as Stern says, climate change is the biggest market failure the world has ever seen. In the actually existing market economy, interest rates reflect the short-run

[37] Stern Review, Appendix to Chapter 2, p.48.

private decisions of those who can afford to participate in financial markets today, not public decisions about intergenerational ethics.

In short, whenever there are data sufficiently precise to justify discounting (a topic discussed below), Stern's general arguments for a low discount rate are persuasive. As Weitzman and others have noted, this alone could be sufficient to flip the outcome of cost-benefit analysis: the high discount rates favored by many economists seem to justify doing very little for now; Stern's low discount rate, applied to the same data, endorses dong much more, much sooner.[38]

This is not to say that Stern's specific discount rate is precisely correct; it is hard to be confident of Stern's 0.1% annual risk of global catastrophe, an admittedly arbitrary estimate. The 1.3% average growth rate of per capita consumption is plausible but far from proven to be correct. A balanced conclusion might be that Stern demonstrates that 1.4% is among the plausible discount rates – and that such low rates have profoundly different implications from rates like 5-6%, used in many other analyses.

On the treatment of uncertainty, Stern is certainly right that this is a critical, under-analyzed feature of the problem. The relative paucity of comments suggests the difficulty of following the details of the Stern analysis of uncertainty. Again, it is more appropriate to interpret the Stern results as showing that thoughtful guesses about uncertainty can have a big effect on the bottom line, rather than attempting to defend the details of the results. As Maddison suggests, the damage estimates involved here are out beyond the frontiers of the economics literature.

Baer argues in a specific case, and Weitzman demonstrates in theoretical terms, that uncertainties and catastrophic risks may be more serious and decisive than Stern recognizes. Valuations for a climate catastrophe, apparently built on Nordhaus estimates from some years ago (which in turn were originally based on an early poll of climate experts' best guesses, plus ad hoc adjustments over the years), seem particularly deficient in empirical support. The PAGE model's Monte Carlo analysis, with 31 parameters allowed to vary, provides an insightful, graphic illustration of the effects of uncertainty in many corners of the analysis; but is it believable that the modelers know the probability distribution for all 31 parameters with any certainty?

Some of the uncertain parameters in PAGE have an enormous effect on the results. Recall that in equation (2), relating damages to temperature, the (unobservable) exponent γ is often set to 2 in other models, but varies between 1 and 3 in PAGE. There seems to be widespread belief that damages will increase more than proportionally to temperature, implying $\gamma > 1$. But how do we know whether γ is 1.3 or 2 or 3, or something in between?

[38] Arrow's conclusion departs from this view of the economic consensus; Arrow accepts Stern's high climate sensitivity scenario, including the estimate for unpriced externalities. In that scenario, the benefits (avoided damages) are so enormous relative to the costs of mitigation that cost-benefit analysis supports immediate action even at a high discount rate. The consensus evaluation sketched by Weitzman uses Stern's normal climate sensitivity scenario, without the externality estimate; on this interpretation, the benefits are of a size, relative to costs, where the choice of the discount rate is crucial.

In the latest version of DICE, Nordhaus offers monetary estimates of damages at 2.5^o and at 6^o of warming which are almost perfectly consistent with $\gamma = 2$, but these two data points are each based on pyramids of indirect and incompletely documented hypotheses.[39] If one accepts Weitzman's reasonable characterization of the world at 6^o of warming as "science fiction," then Nordhaus' data is not – and could not be – persuasive evidence as to whether damages will increase proportionally to the square of temperature (i.e., whether $\gamma = 2$).

Sensitivity analyses by the Stern team (see Table 1) show that using a fixed value $\gamma = 3$, rather than allowing γ to vary between 1 and 3, would make the estimated climate damages skyrocket, increasing by 23.3 percentage points.[40] That is, virtually an additional quarter of worldwide consumption is lost to climate damages, if the (unobservable) exponent in equation (2) turns out to be 3. A sensitivity analysis of this magnitude seems to support Weitzman's suggestion that the worst-case damages of greatest concern are inherently incalculable. The pursuit of greater precision in other parts of the modeling effort cannot eliminate the staggering uncertainty caused by not knowing the exact shape of the damage function.

In the third area of the discussion, the (non-catastrophic) impact estimates and mitigation costs, it is hard to see any points where the critics have damaged the Stern argument. The massively documented Review, its supporting papers, and the detailed responses to the initial criticisms, all illustrate the thoroughness of research that went into the Review.

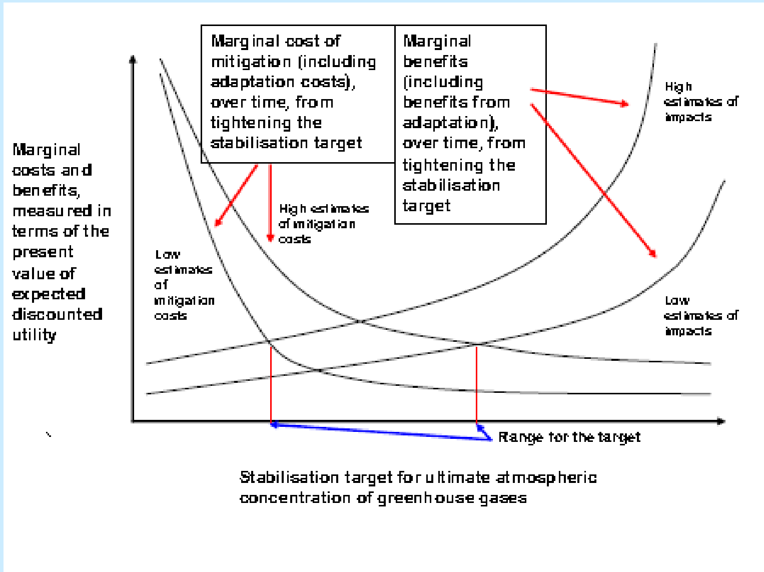
Yet there is one major outstanding puzzle about the cost-benefit comparison, involving the narrow range of plausible targets. Stabilization at less than 450 ppm of CO_2-equivalent is no longer possible at affordable cost, according to Stern, while anything above 550 ppm is too dangerous to consider. Moreover, the costs of reaching 550 ppm are much smaller than the enormous costs of targets just below that level. This pattern is hard to understand; Baer, as well as Tol and Yohe, object that Stern's account of damages should lead to a lower stabilization target.

An abstract argument can be constructed for Stern's narrow window, in terms of the shapes of the damage curve and/or the mitigation cost curve; perhaps it should have been more explicit in the Review. The Review compares costs and benefits in Chapter 13. In that chapter, the sole graphic representation of the comparison (Figure 13.3, reproduced below) is cluttered, and visually suggests that the relevant portions of both curves are fairly flat, and the window of plausible stabilization targets is quite wide. The flavor of the Review's argument would be better captured by an alternative version, such as the one shown below.

[39] William Nordhaus, "Accompanying Notes and Documentation on Development of DICE-2007 Model," April 12, 2007, pp.35-39. Available at http://www.econ.yale.edu/~nordhaus/DICEGAMS/AccomNotes_041207.pdf

[40] Dietz et al., p.144.

Figure 13.3 Schematic representation of how to select a stabilisation level



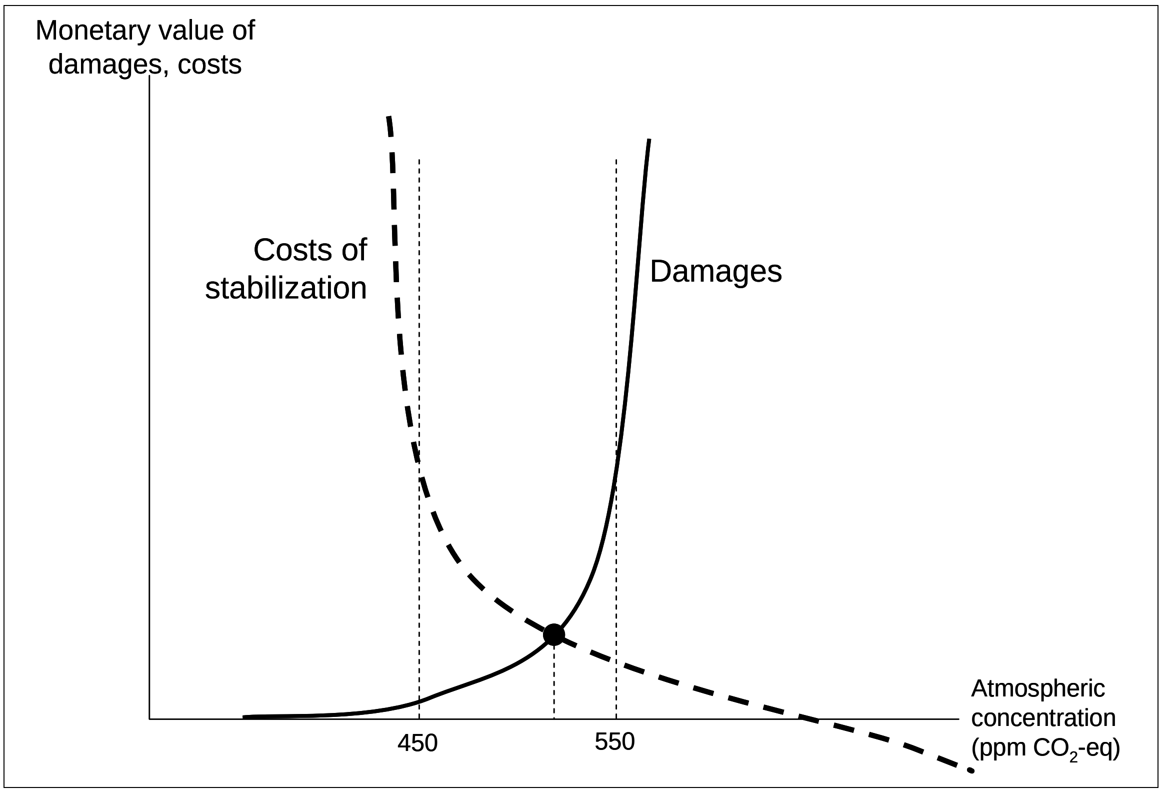
In the alternative graph (below), a narrow window of plausible stabilization targets emerges naturally, due to the limited space between the steep portions of the (dashed) cost curve and the (solid) damage curve.[41] The curves turn essentially vertical at concentrations of about 450 and 550 ppm; thus the intersection is at some point between these levels. This graph is sufficient to create Stern's narrow window; does the Stern Review present grounds for believing that the curves have the shapes shown here?

On the damage side, recall Baer's objection that Stern has understated catastrophic risks at low temperatures and concentrations. This implies that the damage curve should be higher at concentrations such as 450 ppm or even lower. While the Review makes a case that damages rise quickly with concentrations and temperatures, it is not clear that they have provided support for a nearly vertical damage curve at or just above 550 ppm.

On the cost side, the curve shown here implies easy progress in reducing concentrations down to roughly 450 ppm, followed by suddenly harder, more expensive territory below that level. Stern and others have argued persuasively that the early stages of carbon reduction will have low costs (the first steps will have net economic benefits, as indicated by the right-hand end of the cost curve dipping below zero in the graph). It makes sense to project that costs increase as the stabilization target becomes lower. But the notion that the costs of carbon reductions suddenly hit a wall at around 450 ppm, as shown in the graph, would require additional, focused research.

[41] Damages are zero at the pre-industrial concentration of greenhouse gases, 280 ppm, while costs are negative at high concentrations due to the existence of substantial no-cost and negative-cost energy-saving opportunities. The horizontal axis is not drawn to scale here – nor in the Review's Figure 13.3.

However, one critical point made by Stern is easy to explain in terms of this diagram: delays in mitigation will only make costs rise, foreclosing the opportunity to reach lower stabilization targets at acceptable costs. Since greenhouse gases remain in the atmosphere for decades or centuries after they are emitted, the cost of reaching any particular stabilization target depends on how much is already up there, as well as how much is emitted in the future. The longer we wait, the higher the atmospheric concentration will be, and the more drastic the cutbacks in emissions that will be required to stabilize at reasonable levels. In terms of the graph, the cost curve will move steadily upward if we delay – raising both the achievable concentration, and the costs of getting there.



This graphic visualization of the Stern analysis is not an alternative to the issues discussed earlier; rather, it depends on, and, somewhat cryptically, summarizes those issues. The position and shape of the damage curve depends on the discount rate and the treatment of uncertainty, and on damage estimates for specific climate impacts such as sea level rise. The position and shape of the cost curve depends on estimates and assumptions about costs of energy-saving and emission-reducing technologies; questions of discounting and uncertainty also play a role here, although to a much lesser extent than on the damage side.

It would be a difficult task to translate the numerous facets of the Stern analysis into a rigorous diagram along these lines. The conclusions reached in Chapter 13 of the Review, about the relatively narrow window of plausible stabilization targets, imply that the diagram, if constructed, would be shaped somewhat like the alternative sketch above. As indicated above, this aspect of the Stern analysis would need more explicit justification; evidence presented within the Review potentially points toward even lower stabilization targets. On the other hand, the (appropriate) emphasis on uncertainty in many parts of the Review implies that the location of the "optimal" stabilization target, where the two curves cross, is itself uncertain. Definitive information on the shape and position of the curves, particularly the damage curve, will not be available until it is much too late to take the needed actions.

What would a central focus on uncertainty suggest about the Stern Review stabilization targets? One might begin by asking, not what is the most likely value of the damages if the targets are achieved, but rather what is the worst case that is credible under those targets? If there were a precisely defined probability distribution of outcomes expected at 550 ppm, or 450 ppm, the question could be translated into: what does, say, the 98th percentile outcome look like?[42] What is the worst result that has at least a 2% chance of occurring, if the Stern Review stabilization targets are met? Once the question is posed this way, it is easy to understand Baer's suspicion that the Stern targets are too high. For confidence at, say, a 98% or 95% level that climate catastrophe will be avoided, a lower – i.e., more ambitious – carbon stabilization target may be needed.

Such a conclusion casts doubt on the entire analytical framework of comparison of costs and benefits, and begs for a different approach to decision-making – which is the topic of the next, and final, section.

Pricing Lives and Ways of Life

Finally, a fourth area of concern about the Stern Review is only hinted at in the economic commentaries to date. Do the monetary damage estimates, expressed as losses of a fraction of per capita consumption "now and forever," actually convey the seriousness of the problem? As Maddison observes, Stern's estimate of a 1.3% long-term annual growth in real per capita consumption implies that in 2200 the world will be 12.3 times as rich as today.[43] Even a 35% reduction in consumption, a figure mentioned in the Stern Review for an extreme worst-case scenario, would leave the world of 2200 "only" 8.0 times as rich as today. This hardly sounds like a measure of worrisome harms.

Consider the estimate of 20% loss of consumption, offered by the Review as the likely value for the high climate sensitivity scenario with catastrophic risk, non-market damages, and an equity adjustment thrown in. Over the 200-year span of the Stern analysis, in the context of a steadily growing economy, a 20% loss is essentially an insignificant perturbation. After a period of rapid growth, the Japanese economy experienced a decade of stagnation in the 1990s; in recent years, it has begun to grow

[42] The quantitative meaning of "worst case" is itself a debatable policy decision. Here the 98th percentile, or worst 2% outcome, is arbitrarily chosen for comparability with the discussion of Weitzman's comments.
[43] This appears to be a calculation of 194 years of compound growth at 1.3%, i.e. from 2006 to 2200.

again. Suppose that Japan lost 2% of economic growth per year for ten years[44], then resumed its long-term trend rate of growth for the next few centuries. Under that assumption, the macroeconomic problems of the 1990s would have caused Japan to lose 20% of the consumption that would otherwise have been available, "now and forever." In a faster-growing country, such as China, which has reached 10% annual growth rates, a 20% permanent loss of consumption could result from a mere two-year pause, followed by resumption of long-term rapid growth.

Neither Japan's lost decade of growth in the 1990s, nor an imaginary two-year hiatus in China's faster growth, represents a qualitative disaster for the societies involved. No great loss of life, or of a way of life, is involved. To return to the Stern Review's evocative metaphor, the impacts of World War II on Japan and China were of an entirely different nature and magnitude. There were, of course, vast, economically important wartime losses of property and income. But it is difficult to imagine any single monetary estimate that conveys the qualitative impact of a major war. If the expected impact of climate change resembles the effects of the great wars of the early twentieth century, then it does not look much like a 20% loss of consumption in a steadily growing economy, even if that loss is experienced now and forever.

A more up-to-date example illustrates the same point, and provides a model for understanding the role of economic and non-economic aspects of climate damages. In 2005, the impact of Hurricane Katrina on New Orleans and surrounding areas is estimated to have caused as much as $135 billion in property damage; the state of Louisiana as a whole may have lost 15% of its income in the months following the hurricane.[45] On the one hand, these numbers are quite large; on the other hand, they are not even candidates for being the most memorable or disturbing evidence of the damage caused by the hurricane. Rather, the impact of the hurricane is measured in the loss of more than 1,800 lives, the flooding and destruction of countless households and entire neighborhoods, the displacement and impoverishment of several hundred thousand people, and the destruction – perhaps permanent, in part – of a city that has made unique contributions to American music and culture.

The most important impacts of Katrina do not have price tags attached. Some of the lasting impacts could have been ameliorated by a more generous and competent governmental response. This might be viewed as a separate problem; however, climate impacts will at times occur in situations where the resources, generosity, and competence of public authorities cannot be relied on. In other words, the unexpectedly feeble public sector response to Katrina underscores the importance of questions of resilience and capacity to respond to climate change.

---

[44] In fact, the slowdown was even greater than this: Japan's real GDP growth averaged 3.9% per year from 1980 to 1990, then fell to 1.5% from 1990 to 2000. Calculated from Statistics Bureau, Ministry of Internal Affairs and Communication, *Historical Statistics of Japan*, http://www.stat.go.jp/data/chouki/zuhyou/03-21.xls. More recently, Japan's growth rate has risen, although not back to the 1980s level.

[45] See Frank Ackerman and Elizabeth Stanton, "Climate Change: The Costs of Inaction," October 2006, pp.3-4, 15. Available at http://www.ase.tufts.edu/gdae/policy_research/CostsofInaction.html .

What, then, is the importance of the estimates of property damage and income loss from Katrina? It is significant that the losses were many times the cost of building adequate storm defenses in advance – an issue that was frequently raised in the years before 2005. Thus building higher and more reliable levees would have easily passed a cost-benefit test, even without any attempt at valuing externalities; avoided property damage alone would have sufficed to tip the scales in favor of protecting the city. Available, proven methods, long implemented in the Netherlands and elsewhere, would have easily prevented the flooding and destruction of New Orleans.

But this cost-benefit calculation should be done humbly: it is useful, but it is far from the whole story. It may be as far into the story as the monetary damages can take us. Monetary losses do not measure the full human and ecological impact of Katrina, and cannot meaningfully be extended to put a price tag on the whole of the tragedy. Vast sums of wealth and income were needlessly lost – and so were lives, and ways of life. The most important damages are, in a word, priceless.[46] In addition, the ruined houses and urban infrastructure were quite expensive.

The same interplay of economic and non-economic damages applies to the projections of climate change impacts, in the Stern Review and elsewhere. The significance of the economic damages is that, even in their narrowest interpretation, they tip the balance of a cost-benefit calculation, demonstrating that it is well worth it to invest now in an active program of mitigation and adaptation. For this purpose, the narrowest interpretation of damages is more persuasive, staying closer to estimates of actual losses of market income.

As to the ambition of monetizing the entire range of impacts, and telling the entire story in a single number: give it up. The profundity of human and ecological loss implied in the portraits of climate change, especially at higher temperatures, is only cheapened and diminished by pretending that all of it has a price. At the depths of greatest tragedy, as at the heights of proudest collective response, we leave the market far behind. The reason to avoid another world war is not primarily because repairing bombed-out buildings is so costly. The urgency of preparing wisely in advance for two, three, many Hurricane Katrinas is not strengthened by a hypothetical monetary valuation of the lives lost to the storm in 2005. Our moral obligation to protect the lives and livelihoods of future generations is not adequately conveyed by a numerical discount rate – even a low one. How could any estimate of the social cost of carbon bring these overarching ethical concerns back into the calculus of the marketplace, telling us precisely how to think and how much to care about our responsibilities to society, nature, and future generations?

In the absence of complete monetization of climate impacts, a different approach is needed for making policy choices. In this framework, it is no longer possible to carry out the cost-benefit calculation, comparing mitigation and damage costs, as in the Stern Review's Figure 13.3 or the alternative figure presented above. Indeed, that calculation is

---

[46] The logical paradoxes and political mischief associated with assigning prices to such damages are explored in Frank Ackerman and Lisa Heinzerling, *Priceless: On Knowing the Price of Everything and the Value of Nothing* (The New Press, 2004).

doubly impossible, both because of the uncertainty about the extent of damages at any particular atmospheric concentration of CO_2, and because of the lack of meaningful monetary values for many of the damages.

Instead, the immensely valuable compendium of information assembled by the Stern Review can be interrogated from a different perspective. A linked pair of questions must be answered:

- First, what is the maximum atmospheric concentration of CO_2 at which unacceptable climate outcomes can be ruled out with a high degree of confidence?
- Second, what is the least-cost strategy for stabilizing at that concentration?

The first question is the essence of a precautionary approach to policy, in a context of complex and uncertain scientific information. It involves several difficult, but not impossible judgments: about the (probabilistic) link between CO_2 levels and climate outcomes; about which climate outcomes are unacceptable; and about how high a degree of confidence is required that we can avoid those outcomes.

The second question involves cost-effectiveness analysis: given a fixed target, what is the cheapest way to get there? This is far from being easy to answer, for a problem as complex as reducing carbon emissions. Yet it is much more tractable than cost-benefit analysis, since it includes only costs, not benefits (or avoided damages) of mitigation. While challenges and uncertainties will arise in calculating costs, the most difficult problems discussed above are all on the benefit (avoided damage) side of the analysis. Costs are generally well-defined in monetary terms, and subject to engineering and economic research that reduces the remaining uncertainties. Costs occur sooner, on average, than benefits, for this and for many public policy problems. Thus the dilemmas of discounting are much less important for cost-effectiveness calculations.

Such an approach would not be governed by estimates of the social cost of carbon, although it could be made compatible with those figures. The urgency and the required extent of mitigation would be derived from the atmospheric concentration target, which is itself derived from an analysis of the first point at which unacceptable consequences could occur. Once the carbon stabilization target is determined, it is in principle possible to find the least-cost path for reaching the target. The most expensive measure required, in the least-cost path to the target, effectively determines the social cost of carbon. Everything possible that can be done to reduce emissions at a lower cost, per ton of carbon, must already be included in the plan.[47] But in this interpretation, the carbon reduction plan determines the social cost of carbon; this is the opposite of the standard cost-benefit approach, in which the social cost of carbon is used to determine the plan.

In conclusion, the Stern Review takes us a long way toward understanding the economics of climate change, posing many big questions and answering some of them quite well. The arguments against conventional, high discount rates, and the massive review of

---

[47] If not, then the plan could be improved, and overall costs lowered, by substituting the lower-cost measure for other, more expensive steps.

sectoral estimates of damages and mitigation costs, will be hard to improve on, except in issues of detail. The central issue of uncertainty is raised forcefully, though resolved less adequately. The Review offers interesting illustrative calculations of how important uncertainty might be, though it effectively ends up demonstrating how hard it is to put meaningful numbers on the inherently unknown dimensions of the problem.

Finally, the Review episodically suggests an understanding of the priceless, nonmonetary dimensions of loss, which are more serious and profoundly damaging than the – ultimately modest – reductions in long-term growth found by its models. The cost-benefit calculation on the one hand, and the deeper description of damages on the other hand, are important, and importantly separate, dimensions of the discussion. This distinction is unfortunately obscured by the intense debates about exactly how large the monetary damages might be. A better approach would involve deliberation over an acceptable target, followed by calculation of the cost-effective means of achieving the target.

The Stern Review is far from being the last word on every aspect of the economics of climate change – but it is much less wrong than the analyses that preceded it. It has decisively laid to rest the notion that standard economic methods somehow counsel timidity in the face of global crisis.