IAJ The Integrated Assessment Journal
*Bridging Sciences & Policy*
Vol. 6, Iss. 3 (2006), Pp. 65–72

# Some thoughts on the damage estimates presented in the *Stern Review*—An Editorial

G. Yohe
Woodhouse/Sysco Professor of Economics, Wesleyan University, Middletown, CT 06459, USA*

## 1 Introduction

This brief note reviews some of the underlying structure behind the estimates of the costs that could be associated with future climate change that were prepared for the Stern Review (2006). Section 2 accomplishes this task, and notes explicitly the sensitivity of the estimates to not only the range of possible sources of climate impacts now included in the calculations, but also assumptions about the utility discount rate. Section 3 responds to the comparison of these estimates to the economic cost limiting the emission of greenhouse gases. Finally, Section 4 offers some thoughts about context. In summary, there are many questions raised about how the Stern Review computes aggregate economic impacts and evaluates global mitigation costs, and a few are raised here. The basic conclusion that we need mitigation and we need it now is, however, undeniable.

## 2 The Damage Estimates

The damages estimates presented in the Stern Review (2006) were derived by Simon Dietz of the Stern team from Chris Hope's integrated assessment model; Hope (2006) provides documentation of the model (PAGE) and the underlying parameterization of uncertainty. The details are described in some, but not complete, detail in Chapter 6. All are based on a 0.1% pure rate of time preference that discounts logarithmic utility in per capita consumption. Both assumptions play a critical role in computing the reported welfare costs, expressed in terms of percentage losses in *per capita consumption equivalents*. A discussion of this metric follows, but it is not equivalent to percentage losses in gross world product, and it is not (as suggested in the phrasing "now and forever") a measure of actual losses in per capita consumption that would be felt in any particular year along any scenario.

The pure rate of time preference plays a particularly critical role both in calculating losses in per capita consumption equivalent and in determining the

*E-mail: gyohe@wesleyan.edu

reported estimate of the social cost of carbon. The reported social cost of carbon is \$85 per tonne of carbon dioxide. As a single estimate derived from the mean of 1000 runs of PAGE, this figure equates to more than \$310 per tonne of carbon—a very high estimate when compared to the distribution that published estimates reviewed by Tol (2005). This observation may, though, be obscure given the change in units.

Turning now to the various combinations of damages, the first reported 5% reduction in *per capita consumption equivalents*, is derived by running 1000 simulations with market damages and "willingness to pay" to avoid the catastrophic effects of abrupt change. For market damages, the range sampled by PAGE is informed by the usual integrated assessment literature. For catastrophic damages, the analysis follows Nordhaus & Boyer (2000). As accurately described on page 153, the possibility of large losses in regional economic activity begins, for the mean parameterization, to appear at 5 degrees of warming (above pre-industrial levels). Thereafter, the mean parameterization adds adds 10% to the likelihood of catastrophe for every degree of additional warming. Then, using values for relative risk aversion that are much higher than that associated with logarithmic utility (where relative risk aversion equals unity), Nordhaus and Boyer compute a "willingness to pay" to avoid that risk. It is these numbers that add to market damages to form the underlying baseline estimate: 5% reduction in *per capita consumption equivalents* is the mean, but the $5^{\text{th}}$ to $95^{\text{th}}$ percentile range runs from 0.6% to 12.3%.

Non-market impacts add almost 6 percentage points to the mean estimate of damage. They are based on a range from 0% to 1.5% of GDP for a 2.5 degree warming which is extrapolated for higher temperatures. The $5^{\text{th}}$ to $95^{\text{th}}$ percentile range from 2.2% to 27.4% reduction in *per capita consumption equivalents* now straddles a mean of 10.9%.

The next addition comes from adding high climate sensitivities and feedbacks into the calculus. The former is added in the simulations by taking note that 20% of the likelihood for climate sensitivity lies above 5 degrees for many cumulative distributions. The later is accomplished by surveying the literature and shifting the distribution for temperature increase through 2100 up by 0.4 degrees. This calibration anchors an acceleration in the pace warming for every emissions path. The results show a mean reduction of 14.4% reduction in *per capita consumption equivalents* surrounded by a $5^{\text{th}}$ to $95^{\text{th}}$ percentile range from 2.7% to 32.6%.

It remains to explain the definition of *per capita consumption equivalents*. It is a clever tool with which the authors collapse, into one metric, both the enormous variability in per capita consumption across 1000 runs through 2200 and the problem of discounting things back to the present. For the first problem, the authors follow Rothschild & Stiglitz (1970) to compute the mean expected (discounted) utility across all of the runs for each damage calibration (the categories noted above); call this $E\{W_k\}$ for damage calibration $k$ (including $k = 0$ for which there are no climate damages). Then, they compute the initial level of per-capita consumption which, if it were to grow with certainty at 1.3% per year (an assumed "natural growth rate"), would achieve a level of discounted utility exactly equal to $E\{W_k\}$. Call this initial level of consumption $\gamma_k$ to be

**Table 1:** Damage estimates, expressed in terms of percent reduction in *per capita consumption equivalents*, for alternative discount rates.

**Panel A: Base Climate with Catastrophe (from Figure 6.5a)**

| | Pure Rate of Time Preference | | | | |
|---|---|---|---|---|---|
| | **0.1% Stern Review** | **0.1% This Exercise** | **1%** | **2%** | **3%** |
| **Mean** | 5.0 | 4.0 | 1.3 | 0.6 | 0.4 |
| **5th** | 0.6 | 1.0 | 0.4 | 0.3 | 0.2 |
| **95th** | 12.3 | 9.7 | 3.8 | 2.1 | 1.4 |

**Panel B: Base Climate with Catastrophe & High Climate (from Figure 6.5b)**

| | Pure Rate of Time Preference | | | | |
|---|---|---|---|---|---|
| | **0.1% Stern Review** | **0.1% This Exercise** | **1%** | **2%** | **3%** |
| **Mean** | 6.9 | 5.7 | 2.1 | 1.1 | 0.7 |
| **5th** | 0.9 | 1.6 | 0.8 | 0.5 | 0.3 |
| **95th** | 16.5 | 14.4 | 5.7 | 3.2 | 2.1 |

**Panel C: Base Climate with Catastrophe & High Climate & Non-market (from Figure 6.5c)**

| | Pure Rate of Time Preference | | | | |
|---|---|---|---|---|---|
| | **0.1% Stern Review** | **0.1% This Exercise** | **1%** | **2%** | **3%** |
| **Mean** | 14.4 | 10.7 | 3.7 | 1.8 | 1.1 |
| **5th** | 2.7 | 2.4 | 1.1 | 0.6 | 0.4 |
| **95th** | 32.6 | 28.2 | 9.6 | 4.5 | 2.7 |

consistent with the notation in footnote #34 on page 160; the foundation for this calculation can be found in Mirrlees and Stern (1972). The costs reported in the *Report* are the percentage changes between $\gamma_k$ and $\gamma_o$ for every damage calibration $k$. So, they do reflect reductions "now and forever" in an equivalence sense, but there is no expectation or claim that there is a 5% or 11% or 15% or 20% reduction in per capita consumption in 2006 that can be attributed to climate change.

It must be noted that estimates of *per capita consumption equivalents* are highly sensitive to the chosen discount rate and the assumed aversion to risk. The *Report* uses a pure rate of time preference of 0.1% to discount utility, but others have used rates as high as 3%. Table 1 shows the sensitivity of damage estimates to this single parameter for the three loss combinations displayed in Figure 6.5. The second column in each panel produce results for piecewise-linear approximations of the mean, $5^{th}$ and $95^{th}$ percentile trajectories displayed there for a utility discount rate of 0.1%. They do not duplicate the losses reported in Table 6.1 of the *Report* exactly (reported in the first column) because of this approximation and because the discounted utility of the mean trajectory is not equal to the expected discounted utility across all 1000 trajectories. The estimates are relatively close (but slightly lower in most cases) than the figures displayed in Table 6.1. The differences reflect some asymmetry in the distribution of trajectories and the non-linearity of logarithmic utility functions; indeed, for the mean results, they reflect a "risk premium" that can be attributed to the uncertainty with which we view the future of the climate system as reflected by the 1000 runs of the underlying Monte Carlo simulations.

The last three columns of Table 1 report, in turn, comparable estimates for utility discount rates of 1%, 2% and 3%, respectively. Notice that moving from 0.1% to 1% lowers damages reported in *per capita consumption equivalents* by up to 60%; moving to 2% by roughly another 20%, and moving to 3% by yet another 15%. As a result, damages calculated with a 3% pure rate of time preference would support damage estimates that would range from 10 to 20% of the estimates reported in the Review; i.e., damages, in terms of *per capita consumption equivalents* equal to 0.4%, 0.7% and 1.1% instead of the reported 5%, 6.9%, and 14.4% for the three mean cases reported in Table 6.1 and captured in the first rows of Panels A through C of Table 6, respectively.

Table 2 highlights one of the major sources of sensitivity to the utility discount rate by reporting the percentage of reported damages expressed in terms of *per capita consumption equivalents* that can be attributed to the residual term in equation (6) for the mean trajectories—i.e., Table 2 reports the percentage of totals that are derived from the discounted value of damages that would be felt beyond 2200. Notice that these residuals can be quite large for low utility discount rates. Indeed, for the 0.1% discount rate employed in the Review, the residual terms exceed 50% of the total for the mean estimates. For higher discount rates, though, the power of the residual is much smaller.

## 3 Comparisons with the Cost of Mitigation

Notwithstanding this attribution of high damage estimates to the low utility discount rate, their comparison with the cost of mitigation in the *Review* and highlighted in the Executive Summary is a bit misleading. The mitigation costs are, first of all, not computed in terms of *per capita consumption equivalents*; they are, instead drawn from estimates expressed in terms of percentage reduction in gross world product. They are, therefore, not really at all comparable. Secondly, the 1% mitigation cost (with a range from -1% to 3.5%) seems to be derived from estimates of the expense, through 2050, of achieving the requisite 50% reduction in emissions relative to the unconstrained baseline; the number and the range are both drawn from the scatterplot presented in Figure 4 of the Executive Summary. Downstream costs seem to be ignored, but they can hardly be discounted to zero, especially when 50% of the damage is derived from impacts felt after 2200. Finally, the impression is given that all of the computed damages can be attributed as benefit for this investment, but that cannot be

**Table 2:** Percent of damage, expressed in terms of percent of *per capita consumption equivalents* that can be attributed to the residual of the discounted utility calculation along the mean trajectories for alternative discount rates.

| | **Pure Rate of Time Preference** | | | |
|---|---|---|---|---|
| | **0.001** | **0.01** | **0.02** | **0.03** |
| **Base Climate with Catastrophe** | 57% | 18% | 6% | 3% |
| **Base Climate with Catastrophe & High Climate** | 52% | 16% | 4% | 0% |
| **Base Climate with Catastrophe & High Climate & Non-market** | 55% | 19% | 8% | 1% |

true. It is clear from Figure 2 of the Executive Summary that meeting a 550 ppm concentration target would simply put the anticipated increase in global mean temperature somewhere between 1.5°C and 4.5°C. Significant portions of the damages reported would therefore persist, and their values must be subtracted from the reported totals to infer the benefit from this mitigation. The Executive Summary does report a discounted net benefit for the 550 target of $2.5 trillion for "actions taken this year" (pg. xvii). This presumably means for long-term policies initiated now, but the connection between benefits measured in terms of *per capita consumption equivalents* saved and mitigation costs that would certainly extend past 2050 is not clear.

# 4 Broader Context

None of these comments should be construed as arguing, on economic grounds, against the efficacy of implementing policies designed to reduce greenhouse gas emissions in the very near term. They show clearly that damage estimates are sensitive to parameters that are in the purview of policy makers—the discount rate and the treatment of equity considerations come to mind. Other parameters are, however, beyond their control; it follows that adding estimates of damages associated with catastrophic risks and non-market impacts to the calculus of damage estimates is a productive enterprise. It is, though, not the only way to approach new information.

Figure 2 of the Executive Summary (pg. v) is perhaps the most persuasive contribution of the Stern Review (2006) to defining the context within which expanding cost estimates need to be considered; it is replicated here as Figure 1. Readers can use this figure to compare the broad categories of climate risk

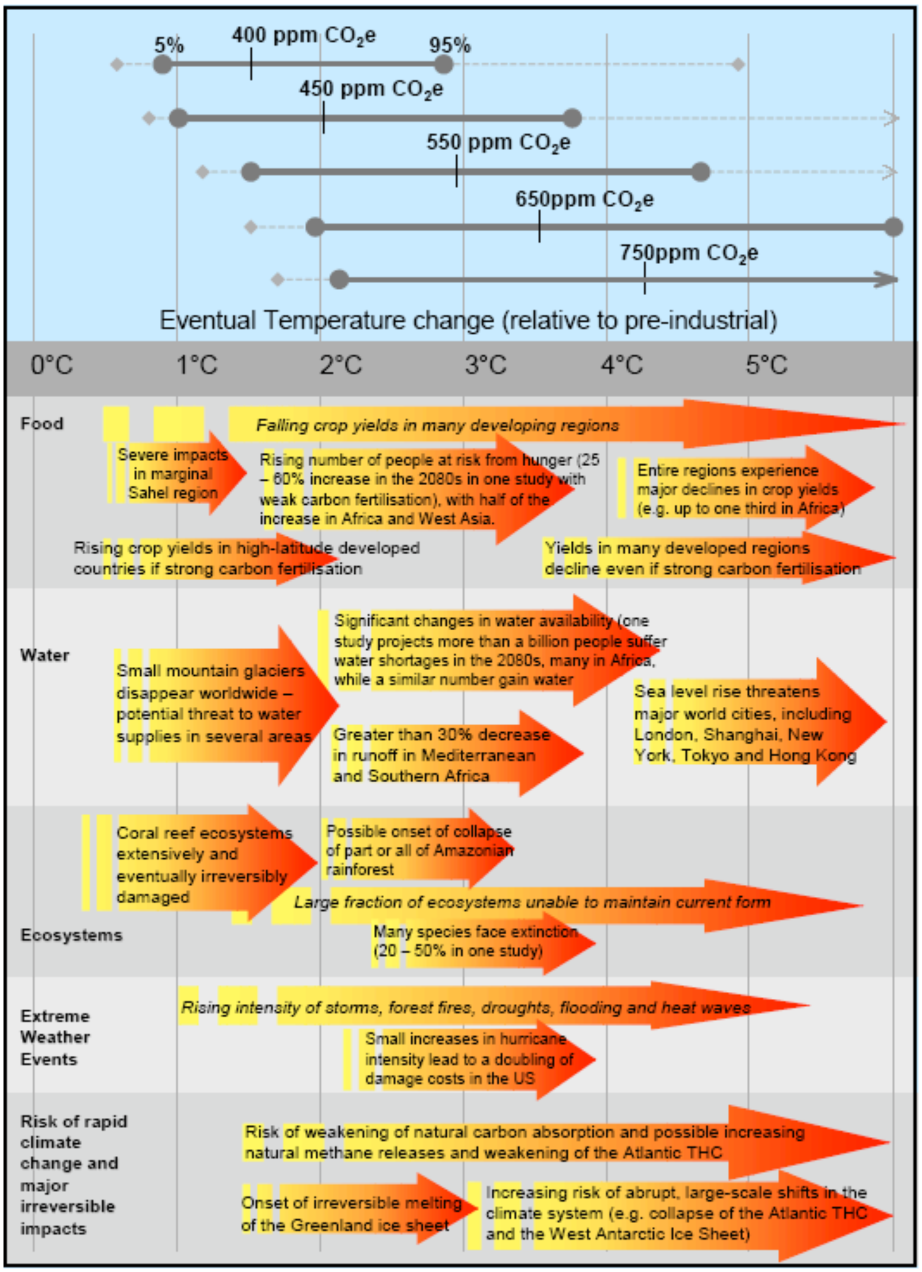


**Figure 1:** Stabilization levels and probability ranges for temperature increases. Source: Figure 2 from Stern (2006)

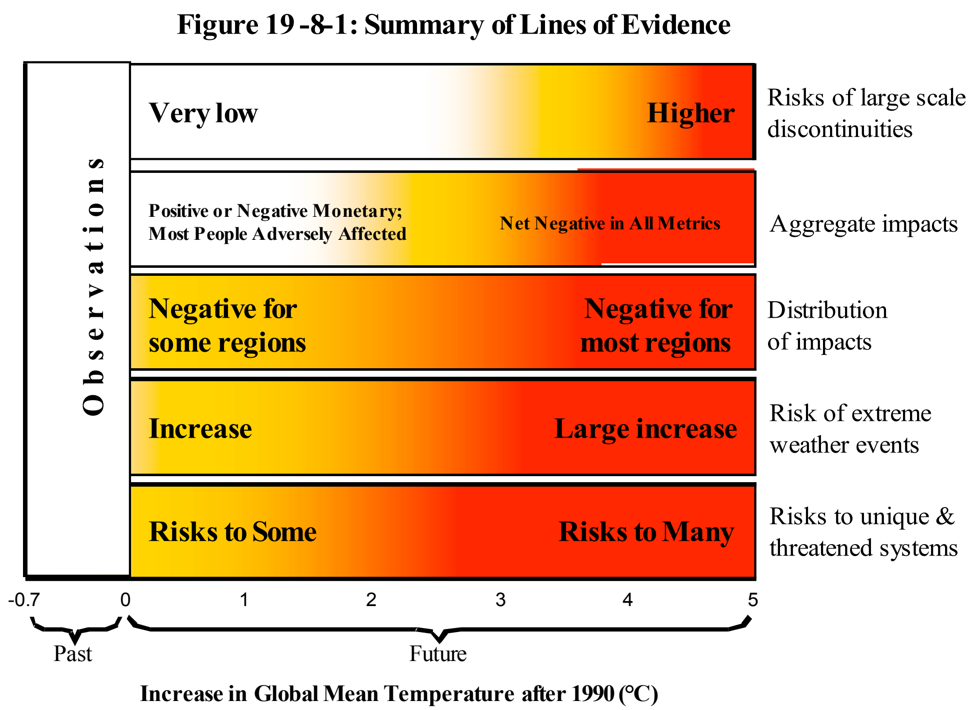


**Figure 2: Sources of Concern and Color-Coded Indications of Vulnerability:** Relative levels of vulnerability along five "Lines of Evidence" or "Sources of Concern" and their sensitivity to increases in global mean temperature were assessed based on the literature available through the middle of 2000. Low vulnerability was indicated by a white or very pale yellow coloration. High vulnerability was highlighted by red coloration; and intermediate vulnerabilities by various shades of yellow and orange. Source: Figure 19-8-1 in IPCC (2001).

displayed in that figure with its antecedent—the "burning embers" diagram published in 2001 by the Intergovernmental Panel on Climate Change (Figure 19–8-1 in IPCC (2001)); it is replicated here as Figure 2. It is immediately clear from such a comparison that new science published since the last IPCC assessment has reduced nearly every temperature threshold for a wide range of high risk impacts. Absent any policy intervention to reduce greenhouse gas emissions, the impacts are therefore closer to the present time than had been thought just 5 years ago.

It is also clear from Figure 1 that concentration limits do not fix anticipated increases in global mean temperature. Suppose, for example, that a reader were to choose 3 degrees as a temperature limit because he or she wanted to avoid dramatic increases in people at risk of hunger or in the likelihood that the Atlantic thermohaline circulation collapses or in the intensity of coastal hurricanes. The figure would then tell him or her that achieving a 550 ppm concentration target would still leave a 50% chance that the planet will experience temperatures that are above his or her threshold of comfort and that a 450 ppm limit will still leave a one-in-five chance. Each reader might pick a different temperature threshold, but few would decide that there is nothing to worry about.

The economic case for near-term policy is made as soon as this conclusion is read from Figure 1. Debates over which temperature threshold is "dangerous" might continue for some time, but *none* of the least cost policy trajectories designed to reach whatever climate target is chosen involve doing nothing for any length of time.

## 5 Bibliography

Hope, C. (2006), 'The marginal impact of $CO_2$ from PAGE2002: An integrated assessment model incorporating the IPCC's five reasons for concern', *Integrated Assessment* **6**(1), 19–56. 65

IPCC (2001), Impacts, adaptation, and vulnerability, Contribution of working group II to the third assessment report, Cambridge University Press. 71, 72

Nordhaus, W. & Boyer, J. (2000), *Warming the World: Economic Models of Global Warming*, MIT Press, Cambridge, MA. 66

Rothschild, M. D. & Stiglitz, J. E. (1970), 'Increasing risk: I. A definition', *Journal of Economic Theory* **4**, 243–255. 66

Stern, N. H. (2006), 'The economics of climate change'. http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm. 65, 70

Tol, R. S. J. (2005), 'The marginal damage costs of carbon dioxide emissions: An assessment of the uncertainties', *Energy Policy* **33**, 2064–2074. 66