A Review of the *Stern Review*

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1. Introduction

The *Stern Review on the Economics of Climate Change* (Stern *et al.*, 2006) was delivered to the Prime Minister and the Chancellor of the Exchequer of the United Kingdom in late October of 2006. A team of 23 people, led by Sir Nicholas Stern and supported by many consultants, worked for a little over a year to produce a report of some 575 pages on the economics of climate change, and their work has certainly drawn substantial attention in the media. Across its 575 pages, the *Stern Review* says many things, and some of the points are supported more strongly and developed more completely than others. Naturally, we agree with some of its conclusions, including the fundamental insight that there is an economic case for climate policy now, and that the cost of any climate policy increases with delay; this is, of course, not really news. We do, though, disagree with some other points raised in the *Stern Review;* here, we raise six issues.

First, the *Stern Review* does not present new estimates of either the impacts of climate change or the costs of greenhouse gas emission reduction. Rather, the *Stern Review* reviews existing material. It is therefore surprising that the *Stern Review* produced numbers that are so far outside the range of the previous published literature.

Second, the high valuation of climate change impacts reported in the *Review* can be explained by a very low discount rate, risk that is double-counted, and vulnerability that is assumed to be constant over very long periods of time (two or more centuries, to be exact). The latter two sources of exaggeration are products of substandard analysis. The use of a very low discount rate is, of course, debatable.

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Third, the low estimates for the cost of climate change policy can be explained by the *Review's* truncating time horizon over which they are calculated, omitting the economic repercussions of dearer energy, and ignoring the capital invested in the energy sector. The first assumption is simply wrong, especially since the very low discount rates puts enormous weight on the other side of the calculus on impacts that might be felt after the year 2050. The latter two are misleading.

Fourth, the cost and benefit estimates reported in the *Stern Review* do not match its policy conclusions. If the impacts of climate change are as dramatic as the *Stern Review* suggests, and if the costs of emission reduction are as small as reported, then a concentration target that is far more stringent than the one recommended in the *Review* should have been proposed. The *Review*, in fact, does not conduct a proper optimization exercise.

Fifth, a strong case for emission reduction even in the near term can nonetheless be made without relying on suspect valuations and inappropriate summing across the multiple sources of climate risk. A corollary of this observation is that doing nothing in the short term is not advisable even on economic grounds.

Sixth, alarmism supported by dubious economics born of the *Stern Review* may further polarize the climate policy debate. It will certainly allow opponents of near-term climate policy to focus the world's attention on the estimation errors and away from its more important messages: that climate risks are approaching more quickly that previously anticipated, that some sort of policy response will be required to diminish the likelihoods of the most serious of those risks, and that beginning now can be justified by economic arguments anchored on more reliable analysis.

These six points are discussed in separate sections before we reach a conclusion.

2. No new estimates

The *Stern Review* argues that "the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP[1] each year, now and forever […] damage could rise to 20% of GDP or more." These are "risks of major disruption to economic and social activity, on a scale similar to

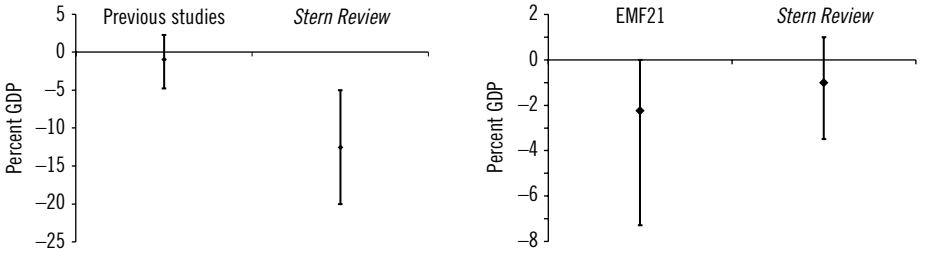
[1] On page 163 of the *Review*, 5% of GDP is in fact the mean for one particular scenario. The 5%ile may be as low as 0.3% of GDP. The 95%ile may be as high as 33%.

those associated with the great wars and the economic depression of the first half of the 20th century". It concludes that "the costs of […] reducing greenhouse gas emissions [to stabilize concentrations at 500–550 ppm CO_{2eq}] […] can be limited to around 1% of global GDP[2] each year".

The authors of the *Review* hope that the implications of these estimates are intuitively clear: there is an overwhelming economic case outlined in the "Summary of Conclusions" for emission reduction because the reported benefit–cost ratio is between 5 and 20. If one looks at the full range of numbers in the report, however, the evidence to support this case is all over the map; indeed, the benefit–cost ratio ranges from 0.09 (0.3/3.5) to infinity (zero abatement costs or better).

To anyone familiar with the economic literature on climate change, these numbers come as a surprise. Figure 1 shows clearly that estimates of the damages associated with the impacts of climate change have never been so high and that estimates of the cost of reducing emissions have never been so low. In the past, benefit–cost analyses have always advocated rather modest emission reduction; see, for example, Kelly and Kolstad (1999). Uncertainty is ubiquitous in our understanding of climate change, of course, so surprises should be expected; but the sources of surprise should be new science and/or new decision-analytic techniques. The *Stern Review* does not present new data, or even a new model. It is fundamentally a literature review supported by some new runs of existing

Figure 1: Estimates of the damage costs of climate change (left panel) and the costs of emission reduction (right panel) according to the *Stern Review* and according to previous studies



[2] On page 211, there is a cost range from –1.0% to +3.5% GDP. Although climate change impacts are counted up to 2200, emission reduction costs estimates stop at 2050.

models. How can it be that such a survey unearths conclusions that are outside the usual range? We turn to that question in the next two sections.

3. The impacts of climate change

The *Stern Review* includes many impacts of climate change in its economic analysis. The *Review*, for example, relies on Arnell (2004) for its treatment of water stress, even though it correctly observes that this work does "not include adaptation" and is therefore severely biased.

Food is another highlighted impact. Climate change would hamper agricultural productivity in some parts of the world, particularly Africa, but is fundamentally a problem in today's world. In all of the socio–economic scenarios used by the *Stern Review*, however, African economies would grow rapidly. This is inconsistent with widespread and persistent famine because middle-income countries would import food (global food production is not threatened by climate change) rather than starve. Furthermore, it is hard to imagine rapid economic growth without substantial improvements in agriculture productivity because, at present, African agriculture is particularly inefficient.

For health, the *Stern Review* makes the same mistake by worrying about people dying of diarrhea and malaria, but these are diseases that can be controlled at little expense when a nation develops sufficiently.

The *Stern Review* also extrapolates increases in damage due to weather-related natural disasters. It uses the estimates of Muir-Wood *et al.* (2006), ignoring the opposite (and peer-reviewed) conclusions by Pielke *et al.* (2005) and Pielke (2005).[3]

In sum, the *Stern Review* consistently selects the most pessimistic study in the literature for water, agriculture, health and insurance.

For refugees, the Myers and Kent (1995) estimates are the highest, and the *Stern Review* duly highlights that "some estimates suggest that 150–200 million people may become permanently displaced". Myers and Kent (1995) was not peer-reviewed,[4] and Norman Myers is a known alarmist.

[3] It is surprising that the *Stern Review* overlooked Pielke's work on hurricane damages, as it was presented at the same meeting as Muir-Wood's work, and Pielke alerted Stern to this (Pielke, personal communication, 2006). Pielke's work on hurricanes is referred to in Chapter 1 of the *Stern Review*.

[4] One of the current authors was on the advisory board of the project that led to the Myers and Kent report. The board was very critical of its findings.

For sea level rise, the *Stern Review* only quotes the "millions at risk" from Nicholls and Tol (2006), choosing to use the metric reported there that ignores adaptation instead of impact measures with adaptation (that can be quite effective) that were included in the same study.[5]

In the chapter on the impact of climate change on development, the *Stern Review* quotes the work of Nordhaus (2006a) and Sachs (2001); they both find that a tropical climate negatively affects economic development. The *Stern Review* ignores the work of Acemoglu *et al.* (2001, 2005) and Easterly and Levine (2003) who argue that climate has had at most a minor and indirect effect in the (distant) past. Moreover, studies by Fankhauser and Tol (2005) and Tol (forthcoming) that incorporate climate change explicitly show that climate change will have a limited effect on development.

In their poverty projections, the *Stern Review* equates income-loss-equivalent-welfare-losses (market impacts only) with actual income losses. Theirs is thus a very crude approximation in part because market impacts add changes in production to the costs of adaptation. They are estimates of change in welfare and not estimates of changes in income (cf. Bosello *et al.*, 2006, forthcoming; Berrittella *et al.*, 2006); moreover, they are regional average estimates, with little information on small spatial scales let alone income classes.

The economic impact estimates of the *Stern Review* are ultimately based on a single integrated assessment model, PAGE2002 by Hope (2006). Although a single model makes for easy presentation, placing all of the emphasis on a single model implies a lack of robustness or, at the very least, diversity. Integrated assessment models differ considerably in their representation of impacts (cf. Tol and Fankhauser, 1998), and the PAGE2002 model stands out for two reasons. Firstly, it accommodates less than a 5% probability that the climate change impacts are beneficial even in the short run; other studies (e.g., Mendelsohn *et al.*, 2000) put that likelihood closer to 10%. Secondly, the model assumes that vulnerability to climate change is independent of development, but it is widely known that adaptive capacity, and thus net sensitivity and perhaps exposure to climate change, is very site specific and path dependent; see, for example, Yohe and Tol (2002). Both assumptions are at odds with the state of the art, but

[5] The *Stern Review* does discuss adaptation, but this discussion is separated from its discussion on the impacts of climate change and from its discussion on optimal climate policy.

no model is perfect. Our only point here is that both of these assumptions imply that the impact estimates are overly pessimistic.

It is impossible for a reader to understand precisely what is in the calculations that underlie the *Stern Review;* it provides too little information in many cases.[6] Reproducibility is, of course, a crucial part of any scientific standard. The *Stern Review* falls well short on this account.[7]

There appear to be no explicit equity weights in the *Stern Review*, for example, but there is a calculation of per-capita consumption certainty equivalents based on discounted (logarithmic) utility (a function of per capita consumption) for which the marginal utility of income varies significantly across the world's distribution of income. The *Review* also adds otherwise unspecified and unquantified "market impacts" (annuitized at 2.1% of GDP), "non-market impacts" (5.9%) and "catastrophic risk" (2.9%) together. Catastrophic risk estimates are drawn from willingness-to-pay estimates to avoid extreme scenarios reported by Nordhaus and Boyer (2000) for relative risk aversion that is higher than that implicit in the logarithmic formulation that underlies the *Stern Review*. The certainty equivalents reported in the *Review* nonetheless are based on a Monte Carlo analysis in which "catastrophic risk" is used as an uncertain parameter; it follows that immediately that risk is counted twice.[8] In addition, the reported certainty equivalents include risk premia that are derived from a depiction of current uncertainties that are cast into the distant future. It follows that the estimation procedure assumes, at least implicitly, that no learning about the climate system and/or the impacts of climate change will occur (or be included in policy deliberations) over the next several centuries. Yohe (2006) suggests that these premia account for about 20% of the reported aggregate damage estimates.

Finally, the *Stern Review* employs a utility discount rate of 0.1%. The implications of miniscule discount rates are widely understood, of course; low discount rates produce high estimates of discounted damages. In this

[6] The *Stern Review* posted more information on its website. See http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_faq.cfm. Although some points are clarified, the web contradicts (revokes?) the report in other places, and adds confusion to some points that seemed clear in the report.

[7] Nordhaus (2006b) argues that the *Stern Review* is a political report, not an academic one.

[8] Essentially, Nordhaus and Boyer (2000) compute the certainty equivalent of the impact of climate change. They then subtract the best guess impact and call the residual "catastrophic risk". Stern *et al.* (2006) add this catastrophic risk to their best guess impact, treat both as uncertain parameters, and compute the certainty equivalent again.

case, though, the discount rate is so low that 40% to 50% of the reported damages for every case come from the "residual"—i.e., economic costs that occur beyond the modeled timeframe of 200 years; see Yohe (2006).[9]

4. The costs of emission reduction

As seen in Figure 1, the range of emission reduction costs used in the *Stern Review* is smaller than the range of costs reported in the latest results from the Energy Modeling Forum under EMF21; see also Weyant (2004), and van Vuuren *et al.* (2006).[10] It is important to note that this EMF exercise surveyed only a subset of existing cost estimates, so its range is an underestimate of the true uncertainty. For two reasons, therefore, the *Stern Review* underplays uncertainty in emission reduction costs while at the same time it emphasizes uncertainties on the damages side of its calculations. Moreover, in taking its estimates of the costs of emission reduction from a commissioned report by Dennis Anderson (2006), the *Stern Review* uses estimates that are more optimistic than previous studies. The *Stern Review* does not present results beyond 2050; for that benchmark year, though, the EMF21 average is a GDP loss of 2.2% compared to 1.0% reported by the *Stern Review*. For 2100, meanwhile, the EMF21 average is 6.4%.[11] Of course, the *Stern Review* stops at 2050, so this acceleration in cost is not captured at all. By truncating emission reductions, the *Review* sketches an overly optimistic picture of the costs of emission reduction.

Equally troubling is the fact that Anderson (2006) reports the results of a simple costing analysis in which the average costs of alternative energy sources with different carbon intensities are compared to one another in a Monte Carlo analysis. The analysis omits not only the impact of higher energy prices that will materialize regardless of climate policy on energy demand (overestimating the costs), but also its impact on economic growth (underestimating the costs) *and* capital stock turnover (a major factor in emission reduction cost calculations).

[9] Analyses of long-term problems such as climate change are split into two parts. Up to the time horizon (2200), calculations are done with a detailed numerical model. Anything that happens after the time horizon is approximated with a simple, analytically tractable model. This is known as the transversality conditions, or residual. If the time horizon is short with respect to the discount rate (as in the *Stern Review*), the residual becomes large and the calculations unreliable.

[10] Anderson (2006) does not include the other greenhouse gases. For EMF21, comparable results were used.

[11] If other greenhouse gases are included, the EMF21 numbers fall to 1.4% and 4.8% of GDP for 2050 and 2100, respectively.

5. Costs, benefits, and targets

The *Stern Review* argues that "the benefits of strong early action outweigh the costs". This action would keep concentrations of greenhouse gases below 550 ppm CO_2 equivalent. We have argued, however, that the *Stern Review* overestimates the impacts of climate change, and therefore the benefits of emission reduction, while it underestimates the costs of emission reduction. Higher than previously estimated benefits and lower than previously estimated costs should have combined to lead the *Stern Review* to recommend more stringent emission reduction than earlier, more standard benefit–cost analyses (see, for example, Azar and Lindgren, 2003; Keller *et al.*, 2004, 2005; Maddison, 1995; Manne *et al.*, 1995; Nordhaus, 1991, 1993, 1994; Nordhaus and Boyer, 2000; Nordhaus and Yang, 1996; Peck and Teisberg, 1992, 1994; Tol, 1997, 1999, 2001, 2002). Intriguingly, the *Stern Review* does not even deviate from earlier UK policy. In fact, the 550 ppm CO_{2eq} target coincides with the climate change target adopted earlier by the government of the United Kingdom (RCEP, 2000). The *Stern Review* should therefore not be understood as a call to revise UK climate policy. Instead, it calls for the same target for stabilizing greenhouse gas concentrations as the previous estimate of HM Treasury (Clarkson and Deyes, 2002)[12] even though it reports a marginal damage cost estimate that is three times as high. The *Review's* estimates of total climate change impacts are about eight times those of the CEC (2005), while abatement cost estimates are only about four times as high. Nonetheless, the *Stern Review* advocates a climate target that is less stringent than does CEC (2005) and devotes no effort to explain these discrepancies.

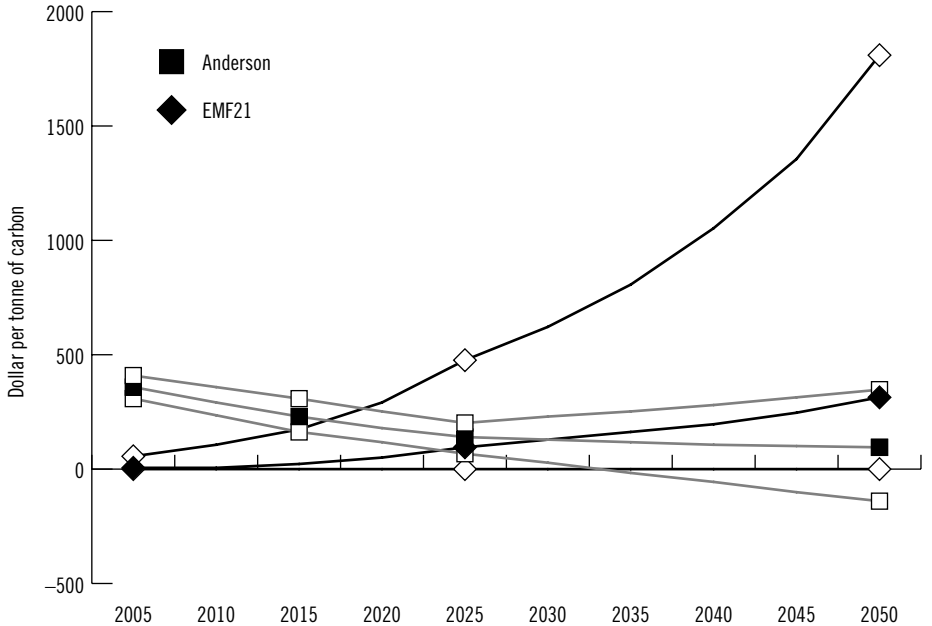
All of these comparisons are evidence that the *Stern Review* does not, in fact, report the results of a benefit–cost analysis. Instead, it simply compares the magnitudes of the costs of abatement for one particular concentration target (around 1% of GDP) to the costs of climate change (5%–20% of per capita consumption) and concludes that the latter justifies the former. There are two mistakes embedded in this conclusion. Neither is necessarily fatal for the conclusion, but both undermine its credibility.

[12] Clarkson and Deyes (2002) has been criticized for being out of step with the peer-reviewed literature (Pearce, 2003; Tol, 2005). The House of Lords Select Committee for Economic Affairs (2005) had warned the UK government for being out of step with the economic literature on climate change—Pearce (2006) adds more detail. The *Stern Review* missed an opportunity to help align UK climate policy to this literature.

Firstly, the costs of climate change do not equal the benefits of emission reduction, because any abatement will only slow (rather than prevent) climate change. It follows that the benefits of emission reduction must be smaller than the estimated costs of climate change (Tol and Yohe, 2006). Secondly, marginal costs should be compared to marginal benefits, rather than total costs to total benefits.

The *Stern Review* is, however, silent on marginal abatement costs, even though it draws from Anderson (2006); there, mean estimates of marginal costs equal $360/tC in 2005 and fall to $96/tC by 2050. Figure 2 compares this mean and its surrounding 90% confidence range to the EMF21 results. Two things are striking. Firstly, the range of Anderson is much narrower than the range of EMF21. Secondly, the marginal abatements costs are rising over time according to the EMF21 survey of multiple models, but they are falling over time according to Anderson (2006). Technological progress, capital stock turnover, the carbon cycle, and discounting all work in favor of rising abatement costs if the discounted costs of achieving any

Figure 2: A comparison of the carbon tax according to Anderson (2006) and EMF21



climate target are to be minimized (Wigley *et al.*, 1996). It follows that Anderson's (2006) abatement policy is thoroughly sub-optimal.

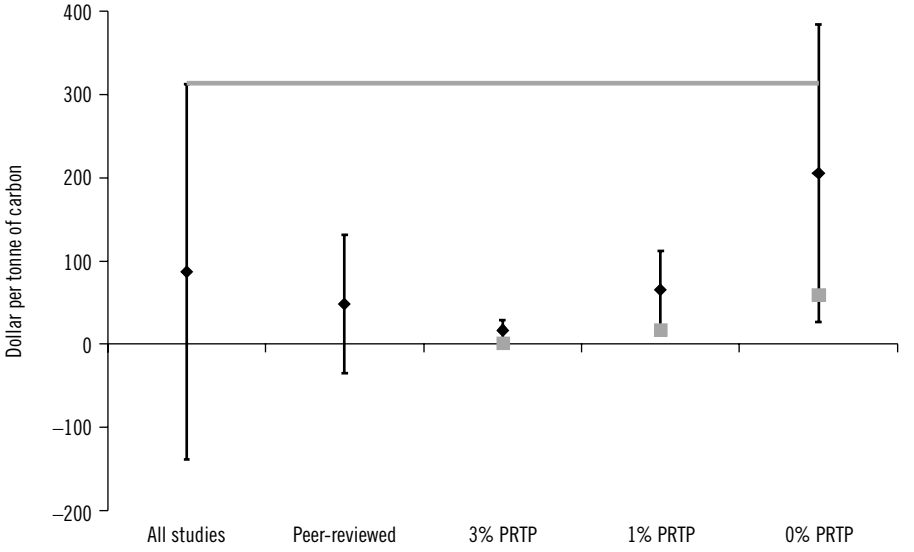
The *Stern Review* does report marginal damage costs: "the current social cost of carbon […] might be around \$85/tCO_2". This number is deemed preliminary and results from PAGE2002 (Hope, 2006).[13] It is nonetheless important to note that \$85/tCO_2 equals \$314/tC, and so it is an outlier in the marginal damage cost literature (Tol, 2005). Figure 3 clearly indicates that the *Review's* estimate is high if all studies are considered, but it is *very* high if the attention is restricted to those studies that were published in peer-reviewed journals. Splitting the sample of peer-reviewed estimates according to the discount rate used, it is also clear that Stern's estimate is even somewhat high compared to other studies that adopt a low discount rate. Recall that the *Stern Review* used a pure rate of time preference of 0.1%. Figure 3 shows results for a 0% PRTP. For comparison, Figure 3 also shows results for FUND2.9. This model is one of the few that has vulnerability changing with development. The contrast is stark, showing clearly that the high damage estimates cannot be explained entirely by the low discount rate. All of the estimation issues identified above play a role in locating the *Stern Review* damage estimates relative to earlier work, even if it is the discount rate that dominates explanations of why, in absolute terms, they are so high.

Returning to the issue of benefit–cost analysis, there is a small discrepancy between the marginal damage costs and the marginal abatement costs in 2005. However, marginal damage costs are typically thought to rise with time. Estimates of the marginal abatement costs reported by Anderson (2006) fall over time, though; and this actually biases *Stern* against stringent mitigation. If Anderson (2006) had started with marginal abatement costs that were slightly lower but rising in 2005 (instead of falling), then optimal emissions reductions derived from the reported damage estimates should have been much deeper. That is, the numbers in the *Stern Review* are inconsistent with its policy recommendation. With the damage estimates that it reports, it should have recommended a more stringent policy.

[13] According to Hope (personal communication, 2006), the marginal damage cost was calculated using a 0.1% rate of pure time preference.

Figure 3: Estimates of the marginal damage costs of CO_2

The figure shows the estimate of the marginal damage costs of carbon dioxide according to the *Stern Review* (tinted line) and according to the meta-analysis of Tol (2005) (diamonds: mean; range: 67% confidence interval) for all studies and various subsamples; also shown are the marginal damage cost estimates according to FUND2.9 (tinted square).



6. Action now?

None of our concerns undermines the fundamental conclusion of the *Stern Review* that immediate action can be justified on economic grounds. To see this, we note simply that Figure 2 in the Executive Summary of the *Review*, for which the underlying detail is provided by Warren *et al.* (2006), provides ample evidence of serious risk from climate change that may have grown since the last global assessment of the literature (Smith *et al.*, 2001). We acknowledge that Article 2 of the United Nations Framework Convention on Climate Change legitimizes looking at those risks to decide what is dangerous. As soon as someone does that, then we know that he or she can identify a temperature threshold of intolerable risk. When he or she looks at the top of *Stern's* Figure 2, however, it becomes clear that no concentration limit, and therefore no emissions limit, can guarantee that the planet will not experience temperatures beyond that

threshold. Indeed, we know that the best that can be achieved by any intervention is a reduction in the likelihood of crossing that threshold. In any case, we argue that *Stern's* Figure 2 makes it clear to nearly every reader that some sort of climate policy designed to reduce the emissions of greenhouse gases will be required.

As soon as that happens, the case for immediate action is made because we know that the economics of exhaustible resources kicks into play. Moving concentration maxima around to manipulate the likelihood of crossing temperature thresholds depends, at least to a first approximation, on cumulative emissions from today until the limit is sustained (and beyond, actually). The policy problem is, therefore, one of computing a scarcity rent for emissions and applying it *to the cost of current emissions*.[14]

Put another way, the economics of dynamics resource management show irrefutably that delay *cannot be a least cost approach* to achieving any climate policy target. Period. There is no need to stuff exaggerated estimates of damages into inappropriate benefit–cost calculations to justify near-term policy. Economic analysis supports immediate action as soon as climate change is recognized as a threat; and Yohe *et al.* (2004) show that this conclusion holds even if the ultimate climate policy target is, at the moment, unknown.

We are not aware of any serious study that casts doubt on the above reasoning. In order to do that, it has to be *certain* (a) that future greenhouse gas emissions will fall rapidly without climate policy; (b) that higher greenhouse gas concentrations do not lead to warming; or (c) that climate change will not have net negative impacts. Such certainty is unwarranted. There is, of course, vigorous debate on the required intensity of immediate action—but recommendations range upwards from a little (rather than no) abatement today (Wigley *et al.*, 1996; Tol, 2005). There is also debate on the appropriate mix of immediate action. Different studies advocate different emphases on immediate emission reduction versus research on carbon-neutral technology versus institutional development to enable future emission reduction—but no study advocates that any of the three is set to zero.

[14] Note that this is not in contradiction to real option theory (Pindyck, 2002), because the intensity of climate policy (as, for example, measured by the price of carbon emission permits) is continuous, and because there are irreversibilities in both emission reduction and climate change.

7. The policy implications of the *Stern Review*

The policy implications of the *Stern Review* are, we fear, bleak. The damage estimates are, themselves, enough to undermine its ability to galvanize support for near-term intervention. Climate change skeptics and climate policy opponents long adopted a strategy that is best summarized by what is reputed to be their mantra: "If you can't convince them, confuse them." Skeptics and opponents will welcome an open discussion of the *Review* as long as it focuses on the economic estimates and not the schematic portrait of climate risks. Why? Because those estimates are vulnerable to valid criticism of the sort described above. Because debate about the credibility of damages estimates will evoke the memory of Benjamin Disraeli and his thoughts about lying with statistics. And because the resulting chaos will keep people from focusing on the real messages of the *Review*. They are three in number.

First of all, climate risks may be approaching more quickly that previously anticipated; i.e., the canaries in the mineshaft may have started to die.

Secondly, it follows that some sort of policy response will be required at some point in time if only to diminish the likelihoods of the most serious of those risks; i.e., we buy insurance against all sorts of threats, so why not climate?

Finally, intervening now can be justified by solid economic argument based on economic efficiency and anchored analysis that cannot be attacked; i.e., it does not take incredible damage estimates to conclude that the least cost approach to reducing climate risks necessarily includes doing something tomorrow if not today.

8. Conclusions

Stopping, or even significantly slowing, climate change will require deep emission cuts everywhere. This project will take 50 years at least, but probably a century or longer. The political will to support climate policy has to span across parties, continents, and generations. We think—and this is supported by a vast collection of scientific studies—that it is in the self-interest of the vast majority of people to support climate policy. Unfortunately, rather than being a voice of reason, the *Stern Review*

provided more mud to be slung right back at the proponents of immediate action. It is a missed opportunity to make a real contribution.

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