Valuation of Damages from Climate Change[1]

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Introduction

It is an honor to be invited to speak at this workshop. I look forward to hearing the latest views of the prominent experts assembled by the organizers. I believe the EPA and other agencies made a good start on estimating the social cost of carbon in the February 2010 report of the Interagency Working Group (2010). Strengthening those estimates has become all the more important with the delay of US climate legislation and the de facto recourse at present to Plan B, in which EPA enforcement and action by the three Regional Climate Initiatives at the state level constitute the interim delivery mechanism for internationally promised US action. I will stress the importance of strengthening the damage estimates in two dimensions: treatment of catastrophic damage and choice of the central discount rate.

Brief Retrospective[2]

Let me first provide a brief retrospective on cost-benefit analysis of climate change. My 1992 book (Cline, 1992) used estimates by the EPA and other sources to estimate that 2.5°C warming from a doubling of carbon dioxide by late this century would impose damages of 1 percent of GDP on the US economy. In order of importance, the damages were in agriculture, electricity requirements for increased cooling in excess of reduced heating; water supply; sea-level rise; loss of human life; tropospheric ozone pollution; species loss, and forest loss. I note that these are broadly the same categories on the agenda of this conference. However, I emphasized that the analysis should cover 300

[1] Remarks at the conference on Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis, Environmental Protection Agency and US Department of Energy, Washington DC, January 27-28, 2011.
[2] For a recent overview, see Cline (2010a).

years, the horizon before major re-absorption into the deep ocean. Using the scientific relationships reported in the first IPCC review, I estimated that over that horizon warming could reach 10°C, increasing damage to 6 percent of GDP in the central case and three times as high in a higher-damage variant. I invoked the Ramsey (1928) discounting method that imposes zero pure time preference, or discounting for impatience, for intergenerational comparisons. With my discount rate of 1.5 percent for per capita income rising at 1 percent, I estimated that -- with modest risk-weighting, a cut in greenhouse gas emissions by one-half at an annual abatement cost of around 3 percent of GDP was warranted on social cost-benefit grounds. Inclusion of catastrophic damages would have reinforced the conclusion. Using his DICE model and a considerably higher discount rate, William Nordhaus (1993) concluded that much less abatement was warranted. In the 1995 IPCC survey of economic modeling results, social cost of carbon by 2010-20 was placed in a range of about \$5-\$7 (1990 dollars) per ton of CO_2 in estimates by Nordhaus as well as some other modelers, but reached \$18 (or \$30 at 2010 prices) in my alternative runs of the DICE model using my discounting (Pearce et al, p. 215; Cline, 1997, pp. 110-17).

Even after an important revision of the DICE model in 2000 that tried to incorporate catastrophic damages based on surveys of expert opinion, by 2008 Nordhaus (2008) continued to estimate low optimal carbon dioxide taxes (\$11 per ton in 2015 and still only \$24 by 2050) and high optimal emissions paths (rising from 30 $GtCO_2$ now to 44 $GtCO_2$ in 2050) and high optimal atmospheric concentrations (480 ppm by 2050 and 660 ppm CO_2 by 2200). In sharp contrast, in his 2007 review for the UK Treasury, Nicholas Stern and his team found that social benefits of greatly exceeded abatement costs of limiting atmospheric concentrations to 500-550 ppm CO_2-equivalent, requiring emissions about one-third lower than the 2000 levels by 2050 and even lower thereafter (Stern, 2007). Stern used the PAGE model with a damage function quite similar to that used in Nordhaus' DICE model, and found that by 2200 global damages under business as usual would amount to 5-20 percent of world product. Using Ramsey's zero pure time preference and considering an infinite horizon thereafter, the Stern Review also placed the equivalent "now and forever" value of unrestrained damages at 5 to 20 percent of world GDP. He placed the abatement cost for the 500-550 ppm ceiling at -1% to +3.5% of world product by 2050, and the average cost at about $50 per ton of CO_2 in 2015, falling to about $30 by 2025. (p. 260) Essentially the same two central analytical features of my 1992 book, Ramsey-type discounting with zero pure time preference and the adoption of a long horizon, led Stern to the same conclusion that much more aggressive abatement was warranted on social cost-benefit grounds than identified by Nordhaus and some other modelers.

At this point Martin Weitzman (2007) entered the debate with a new emphasis on the implications of uncertainty about catastrophic effects. He judged that Stern was probably right for the wrong reason. The pure time preference rate should not be set at zero, but future catastrophes from climate change could be severe enough to drive consumption levels below those of the present and hence discounting for consumption would turn negative. The "fat tail" of the probability distributions of warming and damage are at the heart of this risk, and they introduce uncertainty about the discount rate that should be used. However, Weitzman's mathematics involve a singularity in which the present value of future loss is infinite, so his analysis is difficult to make operational. Sterner and Persson (2007) also arrive at a favorable evaluation of Stern-like aggressive action but argue that this conclusion could be reached "even with Nordhaus' conventional assumptions of a fairly high rate of discount … [if] the escalation of prices for scarce environmental services were taken into account."

Catastrophe Update and Super-Contingent Valuation

Scientific work in recent years has increased the concern we should have about catastrophic effects of climate change. The three catastrophes usually considered are: collapse of the ocean conveyor belt that causes the Gulf Stream and keeps Northern Europe warm; melting of the Greenland ice sheet or collapse of the West Antarctic ice sheet, either of which would raise sea levels by 7 meters ;

and a runaway greenhouse effect as methane is released from clathrates on continental shelves and from permafrost. With respect to the conveyor belt, a 2005 study found that "the Atlantic meridional overturning circulation has slowed by about 30 percent between 1957 and 2004" (Bryden, Longworth and Cunningham, 2005). With respect to the Greenland ice sheet, in a 2005 study Meinshausen (2005) found that " the loss of the Greenland ice-sheet may be triggered by a local temperature increase of approximately 2.7°C, which could correspond to a global mean temperature increase of less than 2°C."

Perhaps the most disturbing new evidence on catastrophic risks concerns massive extinctions as a consequence of an eventual loss of oxygen in the oceans, a buildup in anaerobic bacteria, and the release of hydrogen sulfide from the oceans in amounts toxic for plants and animals. A 2005 study by Kump, Pavlov, and Arthur (2005) found that "fluxes of H_2S to the atmosphere … would likely have led to toxic levels …[that served] as a kill mechanism during the end-Permian, late Devonian, and Cenomanian-Turonian extinctions" (p. 397). In the first of these, the Permian-Triassic extinction event 251 million years ago, some 90 percent of species on land and in the oceans became extinct. Volcanic eruptions in the Siberian "traps" (lava-flows) are likely to have caused sharp increases in atmospheric concentrations of CO_2, methane releases from clathrates, and an increase in global temperatures by levels 6°C (Benton, 2003). "The evidence at hand links the mass extinctions with a changeover in the ocean from oxygenated to anoxic bottom waters" (Ward, 2010, p. 189). A shut-down in the ocean conveyor belt would have caused this changeover, setting the stage for the buildup of anaerobic bacteria and eventual release of hydrogen sulfide. Similarly, a 2007 study found that over the past 520 million years, extinctions were relatively high during warm "greenhouse" phases; four of the five worst mass extinctions were associated with such phases (Mayhew and Benton, 2007).

The time scale for such a phenomenon is unknown, but is probably on the order of thousands of years.[3] Eventually a world free of ice sheets would mean sea levels 60 to 80 meters higher than today.[4]

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[3] Lee Kump, personal communication, November 1, 2007.

If the H_2S hypothesis is correct, humans could probably survive using gas masks out of doors and living in atmospheric-controlled chambers, or at least those who could afford to do so would. However, food supply would be challenging, because of the likely die-off of livestock animals.

These stakes pose an acute problem for cost-benefit analysis. Suppose the time horizon is 2,000 years. Suppose world product stabilizes at $500 trillion (compared to $340 trillion in the EMF-22 scenarios for 2100, and $50 trillion at present), and world population, at 9 billion. The Interagency report's lowest discount factor of 2.5 percent expands $1 over 2,000 years to $\$2.8 \times 10^{21}$ dollars, or $2.8 billion trillion. The policy maker would have to conclude it is not worth spending even a single cent today to avoid the complete elimination of one year's worth of world product 2,000 years from now.

Hopefully, policy makers do not make calculations about such large but long-term stakes in this fashion. It may be helpful to resort to a sort of "super-contingent valuation" thought experiment. Instead of conducting a survey of how much the typical household would be willing to pay to save the polar bear, one could think of how policymakers seem to be expressing revealed contingent valuation of catastrophic damage. Consider the pledges at Copenhagen. The industrial countries have stated that they will provide $100 billion annually by 2020 to help developing countries curb greenhouse gas emissions. Business as usual emissions of developing countries are likely to be 21 $GtCO_2$ by then (Cline, 2010b). The pledges so far from Copenhagen amount to reducing that amount by only 0.7 $GtCO_2$, or by less than 4 percent. Suppose the policymakers believed that by pledging resources, they could induce the developing countries to more than double that effort, attaining a 10 percent reduction. That would amount to a cutback of 2.1 billion tons at $100 billion, implying an average abatement cost of $50 per ton of carbon dioxide. That is twice the central Interagency estimate for 2020. So why not think of the Copenhagen pledges as revealed contingent evaluation by industrial country leaders placing the value of

[4] The lower figure is from Hansen et al (2008) as interpreted in Cline (2010a); the higher figure, from Ward (2010, p. 39).

avoiding catastrophe at about equal to the value of the other global warming damages that have been counted in the models.

Discount Rate Once Again

Interestingly enough, this exercise yields a price that is much closer to the Interagency's low-discount case ($42) and lower than the 95th percentile high-damage case ($81). This comparison brings one right back to the two central issues that have challenged the economics of global warming from the start: the discount rate and proper valuation of catastrophic risk. I have just discussed one important catastrophic risk. Let me say three specific things about the discount rate.

First, returning to proper discounting for a time scale of one or two centuries rather than millennia, I would emphasize that the particular value chosen for one specific parameter makes an immense difference: the so-called elasticity of marginal utility, or the percent decline in marginal utility for a percent increase in per capita consumption. In the Ramsey equation, the discount rate equals pure time preference, which many would agree should be set at zero for intergenerational comparisons, plus the elasticity of marginal utility multiplied by the growth rate of per capita income. Stern's use of unity for the elasticity of marginal utility, or a logarithmic utility function, probably understates how rapidly marginal utility falls off as consumption rises. But the value of 2 used for this elasticity by both Nordhaus and Weitzman probably overstates it. The evidence I would cite is the structure of progressive tax regimes in industrial countries. A parameter of unity would lead to a strictly proportional tax, in which it is considered fair that the poor man pays the same percent of income as the rich man. We observe more progressive structures than that. But a parameter of 2 would mean, for example, that the average (not marginal) income tax on an income of $650,000 would be 79 percent if the tax on an income of $20,000 is 10 percent.[5] That is far more progressive than we observe. The value of 1.5 that I used in 1992 still seems about right to me; in this example it would generate an average tax rate of 42 percent for the rich household, much closer to what we observe.

Second, I urge the Interagency working group to use the long-term Treasury Inflation Protected (TIP) bond as the best measure of the pre-tax risk-free real rate for discounting consumption. Using instead the long-term nominal rate and deflating by actual inflation gives an understatement during the high-inflation 1970s and early 1980s, but an overstatement for the following decades because markets consistently lagged behind the actuality of falling inflation in adjusting inflation expectations. Using the available 20- and 30-year TIP rates since 2004, the real rate has averaged 2.1 percent (Federal Reserve, 2011). When the Interagency's translation to after-tax return at 73 percent of the pre-tax rate is applied, that yields 1.5 percent as the discount rate for consumption. So I would argue that the "descriptive" approach using the observed consumption discount rate should place it at 1.5 percent, more than a full percentage point below the rate of 2.7 percent used in the Interagency report for the same concept.

Third, per capita growth is the other component of the discount rate. The Interagency group expects global per capita income to rise at 2 percent annually through 2100. Actually the EMF-22 projection for 2100 amounts to an annual per capita growth of 1.77 percent for 2010-2100 (Interagency Working Group, 2010, table 2). Moreover, that is at market exchange rates. The growth rate will be lower at purchasing power parity, at about 0.8 times as much based on the Balassa-Samuelson relationship (Subramanian, 2011). The consumption discount rate would then be 1.5 for the elasticity of marginal utility, multiplied by 1.4 percent for ppp growth in per capita income, or 2.1 percent. That

[5] In the constant relative risk aversion (CRRA) utility function, utility from consumption level C is: $U = C^{(1-\eta)}/(1-\eta)$, where η is the absolute value of the elasticity of marginal utility. For a given average tax rate for the poor family, the socially optimal average tax rate for the rich family is the level that just equates the reduction in utility for each of the two families as a consequence of the tax.

would only be for the 21st century. The 22nd century should be discounted at a lower rate because per capita growth would decelerate.

An insurance approach

Even with refinements in discounting, the ultimate difficulty of placing a value on catastrophic effects raises doubts about the use of integrated assessment models to arrive at optimal paths of abatement and carbon dioxide shadow prices. That is why both Stern and Weitzman adopt essentially an insurance approach to global warming policy, even though they disagree on the discount rate. Stern suggests a ceiling of 500-550 ppm for carbon-dioxide-equivalent concentrations. At Copenhagen in December 2009, heads of state set a ceiling of 2°C for eventual warming. Once such targets are set, the social cost problem becomes one of identifying the least-cost way to achieve the target. The discount rate chosen affects the timing of the cutbacks, but their cumulative magnitude is determined exogenously given the climate target rather than endogenously as a function of damage avoided and abatement cost. Even in this approach it would be important to calculate the best estimate of quantifiable non-catastrophic damages avoided, as they would likely cover a considerable portion of abatement costs if not the full amount. Given marginal abatement cost along the least-cost path, the proper price to use for the social cost of carbon is by definition the marginal abatement cost identified for that path.

It turns out that any extra cost paid for this insurance approach may be quite small even when compared to a supposed optimal path using more conventional discounting. Thus, in Nordhaus' (2008) results using the latest version of the DICE model, the difference between the future path of per capita consumption in his optimal path and in a path adhering to a 2°C ceiling (p. 209) is, as Tom Schelling tends to say, no wider than the lead of the pencil being used to draw the graph. The present value of abatement cost in his preferred optimal path that allows eventual warming to reach 3.5°C is a tiny 0.11

percent of the present value of future world product. If instead the 2°C limit is observed, the present value of abatement cost rises to 0.57 percent of world product (Cline, 2010a). The additional insurance costs 0.46 percent of the present value of world product over the next two centuries. That ought to be a bargain if one gives much credence at all to the various catastrophe scenarios. Similarly, in the EMF-22 projections reported in the Interagency review, limiting atmospheric concentrations to 550 ppm CO_2-equivalent would involve abatement costs amounting to only 0.66 percent of world product in 2030 and 1.3 percent in 2100 (p. 16). The insurance approach would thus seem to recommend that the Interagency group include as at least one variant a social cost of carbon path set equal to the marginal abatement cost along either the 550 ppm path or a 2°C ceiling path.

Workshop Issues

I look forward to the discussions in this workshop. Many questions seem relevant for an update of damage valuation. What do the experts now say about storm damage given the experience of Katrina? Was the Fourth Assessment Report of the IPCC understating the pace of likely sea-level rise in light of new evidence? How does the FUND model's finding of initial benefits rather than damages for up to 3°C warming square with Meinhausen's eventual loss of the Greenland ice sheet with only 2°C warming? Where do the agricultural estimates now stand? My own take in my 2007 book was that by the 2080s the losses in agricultural potential would reach about 5 to 15 percent globally, 30-40 percent in South Asia, and 20-25 percent in Africa and Latin America, depending on whether carbon fertilization is included (Cline, 2007). There is also a new category that I hope will be discussed in the session on health impacts: the adverse effect of warming on labor productivity in outdoor sectors in warm climates (Kjellstrom et al, 2008). World Bank modeling of climate policy applies large damage effects in this category (van der Mensbrugghe and Roson, 2010). I would be interested in whether participants in this workshop agree.

Bottom Line

Let me conclude by returning to where I began: I welcome the February report of the Interagency Working Group as a good start. I take some comfort from the fact that for the first two decades, its path for the social cost of carbon is broadly consistent with the Congressional Budget Office (CBO, 2009) estimates of the allowance price for carbon dioxide – or marginal abatement cost -- along the abatement path in the Waxman-Markey bill passed by the House of Representatives in 2009. That bill would have cut US emissions by 83 percent below 2005 levels by 2050, arguably enough to be consistent with global abatement close to what is needed for limiting warming to a range of 2 to 3 degrees C. Thus, the central Interagency estimate of the social cost of carbon dioxide is $26 per ton in 2020 and $33 in 2030; the CBO allowance price for Waxman-Markey is $25 in 2020 and $40 in 2030 (p. 11). However, in later periods the Interagency estimate falls increasingly short of would be needed under Waxman-Markey: $39 versus $70 per ton in 2040 and $45 versus $120 in 2050. I would suggest that given this growing discrepancy, EPA enforcement should take special care when applying the Interagency social cost estimates in decisions affecting new plant equipment designed to be in operation longer than 20 years.

This being said, it does seem to me that more attention to catastrophic considerations and a revisiting of the discounting issue, including the use of TIPs as a guide to the pre-tax consumption discount rate, are likely to lead to a higher path of the social cost of carbon than estimated by the Interagency group in its February report. It is also the case, however, that sooner rather than later it will be necessary to adopt comprehensive legislation on greenhouse gas abatement. When that is done, the American public will no longer have to rely so heavily on the EPA to sort out the right social price of carbon, because their elected representatives will implicitly have made that decision for them by setting the terms of the climate legislation. Super-contingent evaluation will have taken place through the democratic process. In the meantime, political economy could plausibly counsel against any massive shocks in the Interagency Group's revisions of the social cost of carbon. The EPA will need to walk a tightrope between placing too low an estimate that risks the environment, on the one hand, and on the other, placing so high an estimate that it provokes congressional blocking measures (such as threats to block public debt bills unless they include a clause removing the agency's authority to enforce greenhouse gas abatement). Continuing to build on the professional and rigorous approach already begun seems likely to help assure that this narrow path can be successfully followed.

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