The social cost of carbon[1]

Frank Ackerman and Elizabeth A. Stanton [Stockholm Environment Institute, USA]

The social cost of carbon may be the most important number you've never heard of. U.S. climate legislation may or may not make it through Congress this year, but in the meantime, the Environmental Protection Agency is moving ahead, authorized by the Supreme Court to limit greenhouse gas emissions. The Department of Energy is setting energy efficiency standards for residential appliances and commercial equipment, based in part on their contribution to climate change. Other agencies may address the same issues, when their regulations affect energy use and carbon emissions.

The social cost of carbon (SCC), defined as the estimated price of the damages caused by each additional ton of carbon dioxide (CO_2) released into the atmosphere, is the volume dial on government regulations affecting greenhouse gases: The higher the SCC is set, the more stringent the regulatory standards. This white paper explains how economists estimate the social cost of carbon, why the Obama Administration's current analyses are on a path to grossly underestimating it, and why relying on the SCC in the first place may be unproductive.

The EPA, DOE, and other agencies are deciding on values to assign to the SCC in the next few months as part of "rulemaking" processes that are couched in very technical terminology and largely invisible to the general public. In theory, it appears possible to derive the SCC from economic analysis, and the administration appears to have done so. In reality, it's not so simple: Any estimate of the SCC rests on a number of value judgments and predictions about uncertain future events, and so far, the administration has made choices that lead to very low SCC values. In an interim and then a revised analysis, an interagency working group has presented multiple scenarios and possible values for the SCC; the interim analysis suggests, and the revised analysis explicitly endorses, a "central" estimate of $21 per ton of CO_2 in 2010. This amounts to roughly 20 cents per gallon of gasoline, an extremely modest price incentive for carbon reduction. If adopted, this obscure number will have immense practical consequences: A low SCC could result in ineffectual regulations that lead to few if any reductions in U.S. emissions until Congress passes a climate bill.

Even greater harm could result if Congress interprets the $21 SCC as an endorsement of that level for a carbon tax or permit price. This could clash with the widely discussed, science-based goal of achieving an 80 percent reduction in U.S. emissions by 2050, an objective that will almost certainly require a much higher price on carbon. In the revised analysis, the central SCC estimate rises only to $45 per ton (in 2007 dollars) by 2050.[2] If climate economics is (mistakenly, in our view) interpreted as supporting an SCC of only $21 today and $45 by mid-century, it could also be interpreted as advocating only the emission reductions that would result from those prices. That is, working backwards from the proposed SCC, one could infer that the appropriate cap on carbon emissions is much weaker than those found in recent legislative proposals. The resolution to this paradox is that, as we argue in this paper, the $21 SCC is based on flimsy analyses and multiple mistakes. Sound

[1] A Report for the Economics for Equity and the Environment Network, www.e3network.org.

[2] U.S. Department of Energy (2010), "Final Rule Technical Support Document (TSD): Energy Efficiency Program for Commercial and Industrial Equipment: Small Electric Motors," Appendix 15A (by the Interagency Working Group on Social Cost of Carbon): "Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," available online at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/sem_finalrule_tsd.html.

economic analysis would show that the SCC should be much higher, and thus could be consistent with the carbon prices required to achieve science-based targets for emission reduction.

Calculating the SCC is a new undertaking for the administration, and these initial estimates may represent work in progress rather than a final answer. In its first attempts, however, the administration's interagency working group has left itself plenty of room for improvement.

1. The Back Story

A ton of CO_2 is the basic unit of emissions for climate policy, but it may be hard to visualize – especially since it's a colorless, odorless gas that mixes into the air around us. In the United States, one ton of CO_2 is emitted, on average, by:

- A family car every two and half months.[3]
- A household's use of heating and cooking fuel every four months (if energy use were spread equally throughout the year). That's every four years in Hawaii or every six weeks in Maine.[4]
- A household's use of electricity every six weeks.[5]
- The typical use of a microwave oven every seven years or of a refrigerator every 15 months.[6]

U.S. residents emitted 21 tons of CO_2 per person in 2005: 33 percent from transportation, 15 percent from residential electricity, 6 percent from home heating and cooking, and the remaining 46 percent from industry, retail stores, and government.[7]

Each person's annual 21 tons of CO_2 add to the stockpile of greenhouse gases in the atmosphere. The more CO_2, the hotter the average global temperature (the "greenhouse effect"), the faster sea levels rise (warmer waters expand to take up more room, while glaciers and polar ice caps melt), and the more our weather patterns diverge from historical trends (changes to rainfall, more intense storms).

How fast are we making the climate worse? The amount of CO_2 in the air was 280 parts per million (ppm) before the industrial revolution, in 1750, and has now reached 385

[3] Average U.S. passenger fuel efficiency for 2007 was 22.5 mile per gallon (BTS RITA Table 4-23, http://www.bts.gov/publications/national_transportation_statistics/html/table_04_23.html). Motor gasoline emissions coefficient, 19.564 lbs. per gallon (USEIA, Voluntary Reporting of Greenhouse Gases Program, http://www.eia.doe.gov/oiaf/1605/coefficients.html). U.S. miles per passenger car in 2001, 12,000 (USEIA NHTS Table A3, http://www.eia.doe.gov/emeu/rtecs/nhts_survey/2001/tablefiles/table-a03.pdf).

[4] For direct residential emissions calculations see Stanton, E.A., F. Ackerman, and K. Sheeran (2009), *Greenhouse Gases and the American Lifestyle: Understanding Interstate Differences in Emissions*. Stockholm Environment Institute, Economics for Equity and the Environment Network, available online at http://www.e3network.org/papers/NRDC_state_emissions_report.pdf . Data used here are updated to 2005. Number of households in 2005 by state, ACS 2005 B11001, http://www.census.gov/.

[5] For electricity emissions calculations see Stanton, Ackerman and Sheeran (2009). Data used here are updated to 2005. Number of U.S. households in 2005, 111 million (ACS 2005 B11001, http://www.census.gov/).

[6] Ibid. Average energy use for appliances, 200 kWh/year for microwaves, 1100 kWh/year for refrigerators (USDOE Web site, http://www1.eere.energy.gov/consumer/tips/appliances.html).

[7] For methodology and data sources see Stanton, Ackerman and Sheeran (2009). Data used here are updated to 2005.

ppm. Doubling the concentration of CO_2 – on current trends we will reach 560 ppm, double the pre-industrial level, within this century – has been widely expected to increase the average global temperature by 3°C (5.4°F),[8] but recent research has called this into question. Newer studies are suggesting that doubling the atmospheric CO_2 concentration could raise that average temperature by as much as 6°C (11°F).[9] The size of the temperature increase associated with a doubling of atmospheric CO_2, a number referred to as the "climate sensitivity," is crucial to the scientific analysis of climate change.[10]

The purpose of emission reductions is to limit the change in average global temperature and related climate conditions; many scientists believe that any warming beyond 2°C (3.6°F) would put the world at too high a risk of catastrophic, irreversible consequences.[11] Already, CO_2 concentrations are well above pre-industrial levels, and CO_2, once emitted, stays in the atmosphere for a long time. This means that even if we could immediately stop all greenhouse gas emissions, there would still be a gradual temperature increase over the next century. The more we can slow down that increase, the easier it will be for human societies to adapt with careful planning and new technologies. Every ton of CO_2 that we can keep out of the atmosphere slows climate change, helps to hold temperatures under that 2°C threshold, and reduces the risk of the worst kinds of damage.

But reducing emissions also carries a cost – including the price of new "green" energy technologies, and more efficient appliances, vehicles, and heating and cooling systems. The policies used to reach this goal may leave households facing bigger energy bills. So to help determine how aggressively to act to cut emissions, policymakers weigh those costs against the cost of inaction, or of less-aggressive action. That's where the social cost of carbon comes in: It asks, how much will each ton of CO_2 that we release into the atmosphere cost us in damages, both today and in the future? If the answer is a big number, then we ought to make great efforts to reduce greenhouse gas emissions. If it's a small number, then the case for reduction is weaker, and only easy or inexpensive changes seem warranted, at least in narrowly economic terms.

For example, if the SCC had a value of $5 of present and future damages per ton of CO_2, we would be willing to pay up to $5 to prevent a ton from being released (just as you would put $4 in a parking meter to avoid a $5 ticket). But if the cost of a particular measure to reduce emissions had a higher price tag than $5 per ton, we might instead accept those future damages (just as you would prefer the $5 ticket to putting $6 in the meter).

This is why the SCC is so important: The policy choices the government makes would be very different if it estimates climate damages not at $5 but at, say, $500 per ton of carbon

---

[8] Intergovernmental Panel on Climate Change (2007), *Fourth Assessment Report: Climate Change 2007* (AR4).

[9] Hansen, J. et al. (2008), "Target Atmospheric CO_2: Where Should Humanity Aim?" *The Open Atmospheric Science Journal* 2: 217-231, and IPCC (2007).

[10] For recent analyses highlighting scientific concern about climate sensitivity see Roe, G. H., and M. B. Baker (2007), "Why is Climate Sensitivity So Unpredictable?" *Science* 318: 629-632; Clement, A. C., R. Burgman, and J. R. Norris (2009), "Observational and Model Evidence for Positive Low-Level Cloud Feedback," *Science* 235: 460-464; Solomon, S. G.-K. Plattner, R. Knuttic, and P. Friedlingsteind (2009), "Irreversible climate change due to carbon dioxide emissions," *PNAS* 106(6): 1704-1709; and Schellnhuber, H. J. (2008), "Global warming: Stop worrying, start panicking?" *PNAS* 105(38): 14239–14240.

[11] See Ackerman, F., E.A. Stanton, S.J. DeCanio, E. Goodstein, R.B. Howarth, R.B. Norgaard, C.S. Norman, and K. Sheeran (2009), *The Economics of 350: The Benefits and Costs of Climate Stabilization*, Stockholm Environment Institute, Economics for Equity and the Environment Network, available online at http://www.e3network.org/papers/Economics_of_350.pdf , and IPCC (2007).

(in the same way that a $500 parking fine would make you pay much more attention to putting money in the meter). Right now, of course, the price of carbon emissions is zero.

2. Uses of the Social Cost of Carbon

All current proposals for climate policy are based on the price of carbon emissions, whether it's through a carbon tax, market allowances, or through regulation by government agencies.

Carbon tax: Under this option – which is popular with some economists, but anathema in actual policy debates – the price per ton of carbon is applied as a tax on fuels. This can be done either at the well-head and the border, or at the point of consumption (a gasoline tax, for example). The government collects the taxes and can use the revenue for virtually any purpose: to reduce other taxes, to invest in clean energy, to assist workers transferring out of the most polluting industries, and so on.

Emission allowance markets: In a "cap and trade" scheme, a limited number of carbon allowances are issued, and a secondary market forms to buy and sell the permits. In a "cap and dividend" system, carbon allowances would be auctioned off, with the revenue returned to the public. Either way, a market is formed (the secondary market or the government auction) that sets the price of carbon through a give-and-take between buyers and sellers.

These two types of policies are symmetrical: A carbon price results in a reduction to emissions; a cap (or limit to emissions) results in a carbon price set by the market. If $X carbon price results in Y tons of carbon emitted, then a cap of Y tons should result in exactly the same $X carbon price. However, the distributional consequences – who ends up with the tax or allowance revenue in their pockets – depend on the exact provisions of a particular climate policy.

Government regulation: A government agency such as the EPA or DOE can ban polluting technologies, require a set of green technologies, or impose performance standards such as emissions limits. Such regulations can be established with little or no reference to economic analysis, in the classic "command and control" mode; or they can be guided by cost-benefit calculations. Under the latter approach, a policy is approved if its cost (per ton of CO_2 eliminated) is less than the carbon price; and a policy is rejected as uneconomical if its per-ton cost is more than the carbon price.[12] The current analyses of the social cost of carbon will be used to apply this kind of logic to U.S. regulatory proposals.

The administration plans to set the carbon price by using data and analyses taken from current climate economics literature. Their method sounds simple: collect a variety of social cost of carbon estimates from the literature, tweak them for comparability, and use the resulting range of values in decision-making. The next section discusses the numerous problems with the administration's initial attempts at picking numbers for the SCC.

[12] For a deeper discussion of the process of calculating the social cost of carbon, see Stern, N. (2006), *The Stern Review: The Economics of Climate Change*, London: HM Treasury, Chapter 2, available online at http://www.hm-treasury.gov.uk/stern_review_report.htm: and Clarkson, R., and K. Deyes (2002), *Estimating the Social Cost of Carbon Emissions,* U.K. Department for Environment Food and Rural Affairs (DEFRA), Working Paper 140.

3. The Obama Administration and the Price of Carbon

The federal government's estimates of the SCC have been developed by the Interagency Working Group on Social Cost of Carbon, with participation from the Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of the Treasury. The working group's interim estimates were used in DOE's final rule on energy efficiency in refrigerated vending machines[13] in August 2009, and in EPA's proposed rule on tailpipe emission standards for cars and light trucks[14] in September 2009. The working group's revised, current estimates were used in DOE's final rule on energy efficiency in small electric motors[15] in March 2010, and are expected to be incorporated into the final version of the tailpipe emission standard.

The working group's interim and revised analyses of the SCC have several features in common. Both rely heavily on averages of estimates from three climate economics models: DICE, FUND, and PAGE. Both experiment with a range of discount rates for valuing future outcomes (explained below), showing how the estimated SCC depends on assumptions about discounting.

The interim SCC analysis is the simpler of the two.[16] It follows the latest academic publications that present the three models, modifying them only to use differing discount rates. The revised analysis starts from the same point, performs a similar analysis of discount rates, and then goes on to modify the three models to consider a range of possible values for climate sensitivity, and to constrain them to match socioeconomic and emissions scenarios developed in another modeling exercise, the Energy Modeling Forum 22 (EMF-22) studies.[17]

We believe that the working group's interim and revised SCC estimates rely on a biased and incomplete reading of the economic literature on climate change. The methods used to set these values reveal an unexplained confidence in a handful of authors and models, and offer arbitrary, unsupported judgments as grounds for ignoring important alternatives. Most of the errors, omissions, and arbitrary judgments tend to reduce the estimate of the SCC; a corrected version of the same calculations, therefore, would likely result in a larger SCC – and more stringent regulations of greenhouse gas emissions.

---

[13] U.S. Department of Energy, Energy Conservation Program (2009), "Energy Conservation Standards for Refrigerated Bottled or Canned Beverage Vending Machines; Final Rule," 10 CFR Part 431, Federal Register vol. 74, no. 167, Aug. 31, 2009, pages 49914-44968, available online at http://www2.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/bvm_final_rule_notice.pdf.

[14] EPA (2009), "Proposed Rulemaking To Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards," EPA Docket EPA-HQ-OAR-2009-0472, Federal Register vol. 74, no. 186, Sept. 28, 2009, pages 49411-49418, available online at http://www.epa.gov/fedrgstr/EPA-AIR/2009/September/Day-28/a22516d.htm.

[15] U.S. Department of Energy (2010), Appendix 15A (see full reference above)

[16] For a detailed discussion of the interim analysis, see Ackerman, F. (2009), "Comments on EPA and NHTSA 'Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards,' " EPA Docket EPA-HQ-OAR-2009-0472, Federal Register vol. 74, no. 186, Sept. 28, 2009, pages 49454-49789, available online at http://www.sei-us.org/climate-and-energy/Ackerman_Sept2009Comments_on_EPA_GHG.pdf.

[17] The EMF-22 studies were published in a special issue of *Energy Economics* in 2009, available online at http://emf.stanford.edu.

Ethical judgments and omitted values imply that any SCC is incomplete

Some of the serious anticipated damages from climate change, such as loss of endangered species, cannot be quantified or monetized. Much of the climate economics literature used to inform the working group's estimates omits these values entirely, effectively giving them a value of zero. As a result, estimates of the SCC may be too low or logically incomplete, in the sense that they exclude crucial, unmonetized dimensions of climate damages.

Ethical judgments about the treatment of unmonetized damages play a role in any climate policy, complementing the quantitative calculations embodied in the SCC: What importance should be given to, for instance, the loss of endangered species, unique habitats and environments, and human lives and communities? Attempts to assign dollar costs to these priceless values leads to meaningless or offensive valuations (some of which are discussed below). Exclusion of them, however (or banishing them to the netherworld of "caveats" and verbal qualifications that are ignored in practice) amounts to treating them as being known to have no value at all. Ethical questions arise, as well, within the calculation of the SCC, particularly in the treatment of costs and benefits to future generations, a topic we address below.

The arbitrary choice of three models biases the analysis

The economic assumptions leading to the choice of the three models, DICE, FUND, and PAGE, are discussed at some length in the interim analysis. (The revised analysis simply says that these are three widely used models.) The interim analysis first takes Richard Tol's 2008 meta-analysis of estimates of the SCC as a starting point; attention is then restricted to peer-reviewed studies; three specific integrated assessment models – FUND, PAGE, and DICE – are selected, while others are ignored; and an unstated corollary is that the data sets developed by the authors of these three models are adopted without discussion. Each step of this process introduces arbitrary biases into the SCC estimate.

First, Tol's meta-analysis of SCC estimates, which describes itself as a comprehensive review of published research, is in fact a highly personal view of the economics literature, with a strong emphasis on Tol's own work. [18] It includes 211 estimates of the SCC, of which 112 come from Tol.[19] Disproportionate numbers also come from a few other authors and models. Every version of William Nordhaus' DICE model is included, despite the fact that the newer versions were created to update and replace the older versions.

Tol has not published 112 separate studies of the SCC; rather, he has counted multiple scenarios and sensitivity analyses within his own studies as separate estimates. He has extended the same treatment to some, but not all, other economists. For example, the Stern Review,[20] which included multiple scenarios and sensitivity analyses, is treated as only generating a single estimate of the SCC in Tol's meta-analysis. Thus the use of Tol's meta-analysis as a starting point is not a neutral decision; it introduces biases in favor of the work of Tol and Nordhaus, and against the Stern Review, among others.

[18] Tol, R., "The Social Cost of Carbon: Trends, Outliers and Catastrophes," *Economics* (e-journal), Vol. 2, 2008.

[19] Ibid, Table 2, for author counts.

[20] Stern (2006).

Second, insisting on peer review as an absolute criterion for inclusion in the SCC process also creates a bias. Indeed, a principal effect is to rule out consideration of the widely discussed Stern Review, which offered an innovative, rigorous analysis leading to a relatively high estimate of the SCC, $85 per ton of CO_2. Tol and some other economists have criticized the Stern Review for appearing as a government policy report rather than in a peer-reviewed journal. The level of professional review and detailed scrutiny applied to the Stern Review both before and after its publication was, however, far beyond the normal peer review process for articles published in academic journals. Following the publication of the Stern Review, the American Economics Association published a symposium on it in the *Journal of Economic Literature*, and invited Stern to give the prestigious Ely Lecture at the AEA's annual meeting in 2008; that lecture was published in the *American Economic Review*, the highest-status journal in the field.[21]

Third, the FUND, PAGE, and DICE climate economics models are not the only relevant climate economics models. The interim SCC analysis simply asserts without any documentation or other justification that "the FUND, PAGE, and DICE models now stand as the most comprehensive and reliable efforts to measure the economic damages from climate change."[22]

No evidence is offered to support that judgment; the reader must take it or leave it, on the personal authority of the authors of the proposed rule. The judgment, however, is not universal. The EPA's own "Climate Economic Modeling" Web page[23] makes no mention of FUND, PAGE, or DICE, but describes the ADAGE and MiniCAM models, among others. The three chosen models, misidentified as the "most comprehensive and reliable," are in fact among the simplest of all IAMs in current use.[24]

Finally, the data sets developed for FUND, PAGE, and DICE are not the only data that should be considered. The transparency of simple models like these allows a relatively clear view of the data and relationships that drive the model results. For climate economics models in general, including FUND, PAGE, and DICE in particular, the software and model relationships are often less decisive than the data inputs in shaping the results. Extensive experiments with DICE by a range of researchers have shown that with small, reasonable changes to the basic data, DICE can yield very different projections (our own contribution to that "modified DICE" literature is cited below). The procedure suggested in the tailpipe emissions case not only endorses three specific models; it implicitly endorses the data sets offered by the models' authors. Those data sets embody a number of controversial judgments.

FUND, originally developed by Richard Tol, relies on data from numerous studies of particular climate-related costs and impacts by Tol and his coauthors. In the problematic area of monetary valuation of the loss of human life, Tol argues that the value of life in a country depends on how rich it is: As he and two coauthors wrote in a paper on valuation of health, "Following Tol (2002a), we value a premature death at 200 times per capita income [i.e.,

[21] Stern, N., "The Economics of Climate Change," *American Economic Review* (2008), 98:2, 1-37.

[22] EPA (2009), "Proposed Rulemaking" (see full reference above).

[23] http://www.epa.gov/climate/climatechange/economics/modeling.html

[24] Stanton, E.A., F. Ackerman, and S. Kartha, "Inside the integrated assessment models: Four issues in climate economics," *Climate and Development* (2009), 1: 166-184.

average per capita income for the region where the death occurs]."[25] The assumption that higher-income lives are of greater monetary value than lower-income ones is morally offensive.

Tol and his coauthors also conclude, based on a series of mistakes and miscalculations, that the early stages of global warming will cause a huge *reduction* in mortality.[26] Valuing these allegedly saved lives at 200 times their per capita incomes creates a huge, spurious benefit of moderate warming, thereby reducing the net cost of climate damages and the SCC. The multiple mistakes in Tol et al.'s calculation of mortality reduction are explained in our response in the same journal.[27]

Chris Hope, the developer of PAGE, has responded to several objections to particular data inputs by converting them to uncertain parameters, allowing them to vary across a range of different values and looking at the average result. PAGE has produced many different estimates, including the Stern Review results which the interagency working group ignored, as well as the lower SCC values which the working group adopted. In a collaboration between Hope's research group and ours, we came to question PAGE's low projections of climate damages to the United States, even in the Stern Review version of the model.[28] The PAGE data set assumes that developed countries can and do engage in nearly costless adaptation to most climate damages in the next century. In addition, PAGE sets a relatively high temperature threshold for the onset of catastrophic damages, which seems inconsistent with recent scientific discussion of climate risk. Based on changes to these and other assumptions, we worked with Hope to produce several alternate estimates for U.S. and global damages due to climate change, ranging up to five to six times the PAGE defaults used by the working group.

The DICE model, developed by William Nordhaus, is known for its finding that the optimal climate policy is a very gradual one, starting on a small scale and expanding at a leisurely pace; Nordhaus refers to this as the "climate policy ramp." The gradualism of the default DICE projections is driven by the DICE estimate of climate damages, which is surprisingly low. One factor holding down the overall damage estimates is the assumed large benefit of warmer temperatures. On very thin evidence, Nordhaus assumes that most people in the world would be willing to pay for a warmer climate; he concludes that the optimal temperature is far above the current global average.[29] In work in progress, University of California-Berkeley economist Michael Hanemann has used up-to-date information to re-estimate each of the economic impacts of climate change included in the DICE damage

[25] Bosello, F., R. Roson, and R. Tol, "Economy-wide estimates of the implications of climate change: Human health," *Ecological Economics* (2006), 58: 579-591; quote from 585.

[26] Bosello, Roson, and Tol 2006; see Table 1, page 582, for projected changes in the number of deaths.

[27] Ackerman, F. and E.A. Stanton, "A comment on 'Economy-wide estimates of the implications of climate change: Human health,' " *Ecological Economics* (2008), 66:8-13.

[28] Ackerman, F., E.A. Stanton, C. Hope, and S. Alberth, "Did the Stern Review underestimate U.S. and global climate damages?" *Energy Policy* (2009), 37:2717-2721.

[29] Nordhaus, W., and J. Boyer, *Warming the World: Economic Models of Global Warming* (MIT Press, 2000), 84-85. The assumed positive value of warmer temperatures for most of the world is still visible in the "lab notes" documenting the data set for the newest version of DICE, http://nordhaus.econ.yale.edu/Accom_Notes_100507.pdf (page 24, "time use" column). For a critique, see Ackerman, F., and I. Finlayson, "The economics of inaction on climate change: A sensitivity analysis," *Climate Policy* (2006), 6: 509-526.

function, concluding that damages in the United States could be four times as large as the estimates implied by the DICE defaults.[30]

The conclusion is clear: The decision to rely exclusively on the FUND, PAGE, and DICE models and their underlying data sets imposes a narrow, biased filter on the economic analysis of the SCC. If agencies rely on these model results, especially in the absence of other analyses, they will almost certainly underestimate the social cost of carbon.

Casual, undocumented estimates are used to justify the choice of discount rate

Estimates of the social cost of carbon combine present and future damages together as one value, the total impact of an additional ton of CO_2. The process for combining costs from different time periods is called "discounting." The farther into the future that costs take place, the less these costs are assumed to matter in today's decision-making. But discounting also involves a judgment call: Future values can be discounted a lot, so that they have little bearing on our decisions; not at all, so they weigh equally with present costs, or somewhere in between. The higher the "discount rate" that is chosen, the less future costs are valued in present-day terms.[31]

When discounting is used to combine values from a short span of years, a market rate of interest is often taken to be an appropriate discount rate; this may be 5 percent or even higher. In theory, if we knew that climate damages would cost $100 ten years from now, we could invest $64 today at 5 percent interest to cover those costs in the future. To put this another way, at a 5 percent discount rate, a $100 cost ten years from now can be valued at $64 today; anyone who expects to incur a $100 cost ten years from now could put $64 in the bank in 2010, and withdraw $100 in 2020.

However, when discounting takes place across a longer span of time, the logic of using market rates becomes muddied. Climate policy is inescapably concerned with mitigation costs incurred today that will have their greatest benefits a century or more into the future, yet there is no single individual who can compare her own costs today with benefits 100 years from now. The choice of a discount rate for intergenerational impacts is an ethical judgment, not a data point that can be found in the financial pages. Lower discount rates, decreasing rates over time, and even a zero discount rate (no discounting) can be used to show that our society takes seriously the costs to be suffered by future generations.[32]

The interim analysis recommends two alternate discount rates, 3 percent and 5 percent, for use in calculating the SCC, while noting that "decisions based on cost-benefit analysis with high discount rates might harm future generations."[33] Casual estimates and

---

[30] Hanemann, W.M. (2009),"What is the Economic Cost of Climate Change?" University of California-Berkeley. On errors in an influential early analysis of agriculture and climate change coauthored by Nordhaus, see Schlenker, W., W.M. Hanemann and A.C. Fisher, "Will U.S. Agriculture Really Benefit from Global Warming? Accounting for Irrigation in the Hedonic Approach," *American Economic Review* (March 2005) 395-406.

[31] For a detailed discussion of discounting, see Stern (2006) and Arrow, K. J., W.R. Cline, K.-G. Maler, M. Munasinghe, R. Squitieri, and J.E. Stiglitz (1996), "Chapter 4 - Intertemporal Equity, Discounting, and Economic Efficiency," in *Climate Change 1995 - Economic and Social Dimensions of Climate Change, Contribution of Working Group III to the Second Assessment Report of the IPCC,* J. P. Bruce, H. Lee and E. F. Haites, Eds. New York, NY: IPCC and Cambridge University Press: 125-144.

[32] For a more detailed discussion see Ackerman (2009), "Comments on EPA and NHTSA 'Proposed Rulemaking.' "

[33] EPA (2009), "Proposed Rulemaking" (see full reference above).

unsupported judgments are used to justify discount rates that are inappropriately high for an analysis that spans several generations. The Office of Management and Budget guidelines encourage sensitivity analysis with discount rates below 3 percent for intergenerational problems.[34] The revised SCC analysis takes a timid step in that direction, adding a discount rate of 2.5 percent, along with 3 percent and 5 percent.

Catastrophic climate risk is left out of the calculations

The administration's estimates of the social cost of carbon largely omit the risk of catastrophic climate damage. (DICE includes the expected value of a moderately catastrophic economic downturn, with a magnitude based on a very old opinion survey; PAGE includes a Monte Carlo analysis of the risk of a similar-sized catastrophe; FUND ignores the issue.) The interim analysis mentions this issue only briefly in its "caveats" to its estimates; the revised analysis discusses catastrophic risk at greater length, suggesting it as an area for future research on the SCC.

In fact, the treatment of catastrophic risk is one of the most important parts of climate economics, and has been the subject of extensive theoretical analysis and debate. Martin Weitzman's important recent work on uncertainty suggests that policy should be directed at reducing the risks of worst-case outcomes, not at balancing the most likely values of costs and benefits.[35] This fits well with a large portion of the prevailing discourse on climate change: The expected damages are important and costly; the credible worst-case outcomes are disastrously greater. The urgent priority is to protect ourselves against those worst cases, not to fine-tune expenditures to the most likely level of damages.

Protection against worst-case scenarios is familiar, though it takes us outside the realm of cost-benefit analysis, into the discussion of insurance policies. Insurance is normally taken out against events which, on average, are unlikely to occur: The average U.S. housing unit can expect to have a fire every 250 years, so the most likely number of residential fires you will experience in your lifetime is zero.[36] Moreover, insurance is guaranteed to fail a simple cost-benefit test – the average value of payments to policyholders must be less than the average value of premiums, in order for any insurance company to remain in business.

Policy designed from this perspective would not be framed in terms of cost-benefit calculations. Rather, it would begin with adoption of a safe minimum standard, based on the scientific analysis of potential risks. The economic analysis would then seek to determine the least-cost strategy for meeting that standard. For example, we recently examined, together with a group of coauthors, the costs of lowering atmospheric CO_2 concentrations to 350 ppm, a level now advocated by a growing number of climate scientists and policy analysts.[37] The best available estimates suggest that the costs would be noticeable, but manageable. The

[34] As cited in EPA (2009), "Proposed Rulemaking."

[35] Weitzman, M. (2009),"On Modeling and Interpreting the Economics of Catastrophic Climate Change," *Review of Economics and Statistics*, 91:1-19; see also Weitzman, M. (2007) "A Review of the Stern Review on the Economics of Climate Change," *Journal of Economic Literature*, 45:703-724. For a non-technical presentation of the Weitzman analysis of uncertainty as applied to climate change, see Ackerman, F. (2009), *Can We Afford the Future? Economics for a Warming World*, London: Zed Books, Chapter 3.

[36] See Ackerman (2009), Chapter 3, for details.

[37] Ackerman et al. (2009), *The Economics of 350* (see full reference above).

risk of spending "too much" on clean energy alternatives pales in comparison with the risk of spending too little and irreversibly destabilizing the earth's climate.

The revised analysis adds complexity, but not insight

The features, and problems, described above are common to both the interim and revised calculations of the SCC. The more elaborate analysis in the revised calculation, used in the small electric motors case, adds two more major features.

First, the working group performed a Monte Carlo analysis of the effects of scientific uncertainty about climate sensitivity. This appears to be done in a rigorous, appropriate manner. One might expect the result to be a much higher SCC, but that is not the case. We made a similar, unexpected discovery in recent research with DICE: Varying the climate sensitivity alone caused surprisingly little change in the model results.[38] In schematic terms, climate sensitivity governs the model's translation of CO_2 concentrations into temperature increases, but the model's damage function translates temperatures into economic damages. If the damage function is sufficiently "optimistic" – or perhaps "Polyanna-ish" – then even relatively high temperatures may impose limited costs, and therefore inspire limited policy responses. The DICE damage function rises at a leisurely pace as the world gets warmer, and does not project that half of global output is lost to climate damages until warming reaches 19^{o}C (34^{o}F), far above the range of temperatures normally considered in even the most disastrous climate scenarios.

Second, the working group chose a set of macroeconomic growth and emissions scenarios for use in the three models. Rather than using relatively familiar IPCC scenarios, the working group opted, with little explanation, for a group of five scenarios extracted from the Energy Modeling Forum 22 (EMF 22) process. EMF 22 compared the latest projections from about a dozen climate economics models (including FUND, but not DICE or PAGE). The working group took four distinct business-as-usual scenarios, from four different EMF 22 models, and one policy scenario achieving moderate emissions reduction. It then used these scenarios in DICE, FUND, and PAGE, and averaged the results. For DICE in particular, significant software modifications were required to reproduce the EMF scenarios.

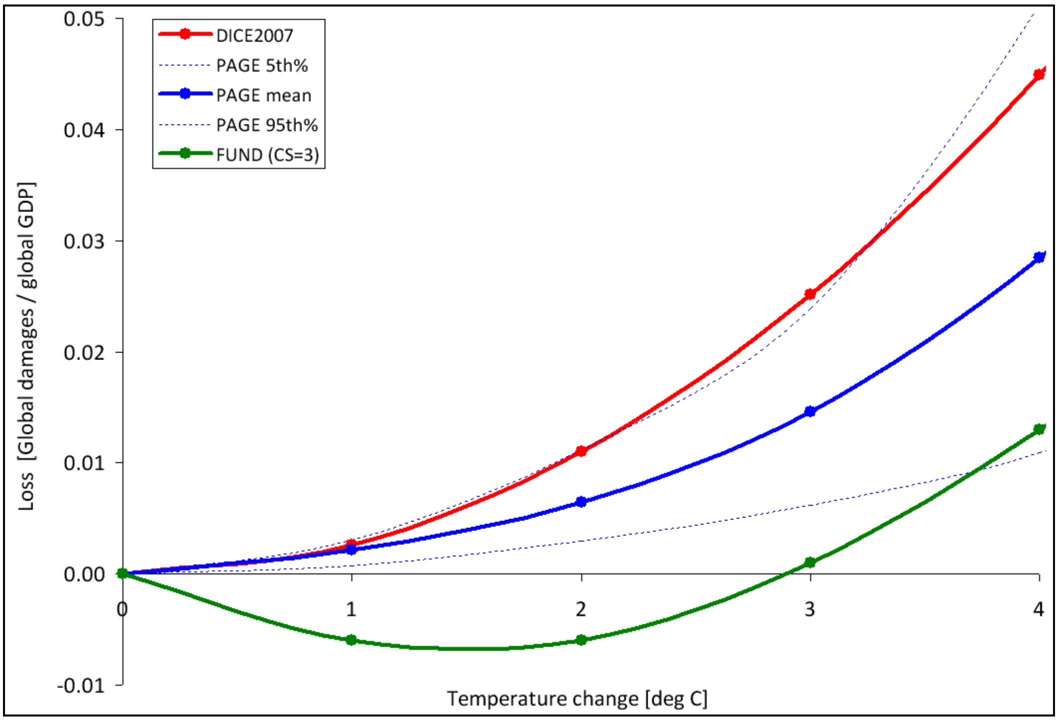
This hybrid modeling exercise is unsatisfying all around: It has neither the benefits of relative familiarity with the three simple models and the standard IPCC scenarios, nor the advantages of applying the more complex, larger models used in EMF 22. If such large pieces of the EMF 22 apparatus needed to be used, why not review the findings of the EMF 22 models as a whole?

One conclusion from the revised analysis is that FUND is an outlier among climate economics models. As the working group's Figure 1B (reproduced here) shows, DICE and PAGE project modest but positive damages at low temperature changes, but FUND projects net benefits (in the graph above these are represented as negative – below zero – costs) to the world from warming until the world is almost 3^{o}C (more than 5^{o}F) hotter. That is, FUND believes the world will be better off as a result of the first several decades of global warming. With a high enough discount rate, those decades of desirable warmth outweigh the far future when we move beyond 3^{o}C; at a 5 percent discount rate, FUND's estimate of the SCC is negative![39] According to FUND, that is, at a 5 percent discount rate, it would be appropriate to

[38] Ackerman, F., E.A. Stanton, and R. Bueno (2010), "Fat Tails, Exponents, and Extreme Uncertainty: Simulating Catastrophe in DICE," forthcoming in *Ecological Economics.*
[39] See U.S. Department of Energy (2010), Appendix 15A (full reference above), page 27, Table 3; see also EPA (2009) "Proposed Rulemaking," page 49615, Table III.H.6–1, for comparable results in published FUND studies.

provide a (small) subsidy to those who emit carbon, because they are accelerating the arrival of the gloriously hotter mid-century years.[40]

Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE



Source: U.S. Department of Energy (2010), Appendix 15A (see full reference above), page 11, Figure 1B.

Our reading of these results is that the FUND model needs to be towed back to the shop for major repairs. The interagency working group, however, has concluded that FUND is an appropriate choice for its short list of three models providing estimates of the SCC for U.S. policy purposes.

The results of the analyses will be interpreted as clustering around $21 per ton

Neither of the analyses resulted in a single bottom-line estimate of the one and only SCC. Both produced multiple figures, primarily reflecting differing assumption about the discount rate. The figures are presented in Table I.

[40] At higher discount rates, FUND's estimates of the SCC move into barely positive territory: $6 per ton at a 3 percent discount rate, and $14 per ton at 2.5 percent, still far below DICE and PAGE. DOE (2010), Table 3, p. 27.

Table I: Estimates of the SCC in two recent analyses

	Social cost of carbon, 2010 (in 2007$)	
	Interim analysis	Revised analysis
Fixed discount rates, mean estimates		
5 percent	$5	$5
average of 3 and 5 percent	$21	–
3 percent	$37	$21
2.5 percent	–	$35
Other estimates		
discount rate declines from 5 percent	$11	–
discount rate declines from 3 percent	$61	–
95th percentile risk, 3 percent discount rate	–	$65

Note: Published SCC values in the interim analysis are for 2007; we have escalated them at the recommended 3 percent annual real growth rate to yield figures for 2010, comparable to the revised values.

Both the interim and revised analysis provided three estimates involving fixed discount rates and mean risks; at first glance the ranges of numbers are very similar. The definitions, however, are different: At a 5 percent discount rate, the SCC is the same for both, but at 3 percent the revised SCC is $21, while the corresponding interim value is $37. At least at lower discount rates, the two analyses embody very different views of the damages caused by greenhouse gas emissions. Due to the accidents of presentation, however, each has a (differently defined) “central” estimate, in this group, of $21.

Each analysis also considered one alternative assumption. The interim analysis examined the implications of discount rates that decline over time, starting at either 5 percent or 3 percent. The revised analysis calculated the 95th percentile risk, from its Monte Carlo analysis of climate sensitivity, using its “central” estimate of a 3 percent discount rate. The uppermost values projected are, coincidentally, not far apart, though again the definitions differ. While the upper values are academically interesting, both analyses are being taken as projecting that the SCC is $21 per ton of CO_2 in 2010, measured in 2007 dollars, or roughly 20 cents per gallon of gasoline. It is hard to reconcile a carbon price that is well within the range of normal price fluctuations at the gas pump with the policy goal of substantially reducing carbon emissions.

5. Conclusion and Recommendations

The administration’s narrow proposed range of SCC values, with a likely “central” estimate of $21, is a function of its choice of a limited range of underlying studies, high discount rates, and insufficient emphasis on the risk of catastrophic climate damage. Different choices at several points in the methodology would have resulted in a far higher SCC and, as a result, more stringent and more expensive emissions reduction would be considered economical.

The discussions of the SCC in the working group analyses to date do not contain enough information to construct a better estimate. Instead, there is a need for more extensive research, examining the full range of available studies of climate damages and costs, and analyzing assumptions about the risks and magnitudes of potential climate catastrophes. If one or more of the simple climate economics models highlighted in the rulemaking process –

DICE, FUND, and PAGE – are to be used, then the default data sets supplied by the modelers need to be independently validated against the latest research on climate damages and other input assumptions. FUND, in particular, needs to be re-examined to understand its projections of net benefits from warming, and to consider the potential need for modification.

Additional research on climate damages could address the potential disconnect between science-based and economics-based targets for emission reduction. If, as climate science forecasts with increasing urgency, there are severe risks from just a few degrees of warming, this should be reflected in the economic estimates of damages. Models which claim that the first 3^oC of warming are beneficial to the world will inevitably endorse very little reduction in greenhouse gas emissions; models which imply that 2^oC is the limit for avoiding serious risks of destabilizing the earth's climate will suggest much greater reduction. They can't both be right. There is no reason to think that three small economic models contain insights into climate dynamics superior to those from the massive, extensively tested general circulation models of climate science. Thus it is time to construct an economic analysis consistent with the concerns and constraints that emerge from the science of climate change.

There is a related need for policies to address the crucial but unmonetized aspects of climate impacts, and to face the ethical choices raised by these impacts. These choices are difficult to fit into the cost-benefit framework implicit in the SCC calculation.[41] An alternative approach could assert that it is essential to set an absolute limit on climate damages, and therefore to keep emissions and temperature increases under strict ceilings – such as 350 ppm of CO_2 in the atmosphere, or no more than a 2^oC temperature increase. This would lead to a cost-effectiveness analysis, seeking the least-cost scenario for achieving the needed emission reductions. That scenario would consist of adopting all the lowest-cost reduction opportunities, starting from the measure with the lowest cost per ton of avoided emissions and adopting additional measures in order of their expense. In a cost-effectiveness framework, the carbon price is still important to decision-making, but it is calculated on a different basis. Instead of an SCC, the carbon price would instead represents the per-ton cost of the most expensive mitigation measure that is required to meet the emission reductions target.

How high might an alternative carbon price turn out to be? The United Kingdom, which pioneered the use of SCC estimates for policy purposes, abandoned calculation of the SCC altogether in 2009, and now bases its carbon price on estimates of mitigation costs (as would be required under a cost-effectiveness approach). The latest estimate is a range of $41-$124 per ton of CO_2, with a central case of $83 – which is very close to the estimate of the SCC in the Stern Review.[42] An expanded calculation of carbon prices for the United States should at least explore prices in this range, and should be open to considering the full range of implications of the extensive research that is needed to compute a better estimate of the price of carbon emissions.

---

[41] Ackerman, F., and L. Heinzerling (2004). *Priceless: On Knowing the Price of Everything and the Value of Nothing*, New York, NY: The New Press.

[42] U.K. Department of Energy & Climate Change (2009), "Carbon Appraisal in UK Policy Appraisal: A Revised Approach," available online at http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/valuation/valuation.aspx. Pounds sterling converted to dollars using an exchange rate of £1.00 = US$1.625.

SUGGESTED CITATION:
Frank Ackerman and Elizabeth A. Stanton "The social cost of carbon", *real-world economics review*, issue no. 53, 26 June 2010, pp. 129-143, http://www.paecon.net/PAEReview/issue53/AckermanStanton53.pdf