Comments on

Standards of Performance for Greenhouse Gas Emissions for New Stationary Sources: Electric Utility Generating Units

77 Fed. Reg. 22,392 (April 13, 2012) Comments on

the Benefits of Carbon Reductions from the Proposed Power Plant New Source Performance Standards

submitted by

Natural Resources Defense Council
Sierra Club
Earthjustice

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I. Introduction

In the regulatory impact assessment (RIA) accompanying the proposed new source performance standards (NSPS) for power plants, EPA compared the environmental damages of a hypothetical newly constructed natural gas combined cycle plant with those of a hypothetical newly constructed conventional (non-CCS) coal plant in 2020. The comparison was purely illustrative, as the new coal plants are not projected to be built in the base case, in the absence of the proposed NSPS.

EPA presented this calculation in terms of $/MWh, comparing the relative environmental benefits of natural gas over coal on a per megawatt hour basis. Included in the measure were separate benefits-per-ton estimates for reductions in SO_2 and CO_2.

We commend EPA for developing this practical and very useful metric, as it allows ready translation of an abstract aggregate number (total pollution damages) into something meaningful and accessible to the public: how much it costs per unit of electricity in public health and environmental costs, on top of production costs.

EPA found that a new coal-fired plant would produce $3 to $34 per MWh more in carbon pollution damages (.3 to 3.4 cents per KWh) than a natural gas-fired plant, depending upon the assumed discount rate. For SO_2, the coal plant would generate $6 to $16 more per MWh in damages (.6 to 1.6 cents per KWh), depending upon discount rate and health impact function (see Pope and Laden impact function studies cited in the RIA).

While we applaud inclusion of these estimates in the RIA, at the same time we have concerns with how the benefits-per-ton estimates for CO_2 pollution were calculated and presented. To calculate carbon damages, EPA used the social cost of carbon (SCC) – a monetized value of the marginal benefit of reducing one ton of CO2 on climate change – as estimated by the Interagency Working Group on the Social Cost of Carbon (February 2010)[1].

The Working Group's SCC is flawed in several respects that lead to significantly underestimating the benefits of curbing CO_2 pollution. NRDC recently made recommendations as to how to improve the estimates of the SCC, in comments submitted for the proposed NSPS for the oil and gas industry in Fall 2011. Those comments are attached to these. Some of our recommendations focused on changes EPA could have made during the oil and gas rulemaking, and could make within the timeframe of this rulemaking. Others were longer term suggestions for the EPA and Working Group to consider in future revisions of the SCC.

EPA rejected many of the near term suggestions in its final action on the oil and gas NSPS, while promising to take the longer term recommendations into consideration when revising the SCC. These comments therefore reiterate NRDC's near term recommendations— recommendations we believe can be implemented within the timeframe of this rulemaking – and explain why EPA's rejection of them in the oil and gas rulemaking was not justified.

Our concerns focus on the choice of discount rates used to estimate the SCC, the Agency's refusal to calculate benefits using a 99th percentile SCC estimate, and the limited explanation of what the SCC measures. The Agency still has not adequately defended its discount rates, nor provided adequate information as to what is (and is not) contained in the SCC models.

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[1] U.S. Government (February 2010), Interagency Working Group on Social Cost of Carbon. Technical support document: social cost of carbon for regulatory impact analysis under Executive Order 12866.

Section II provides background information on the SCC, Section III our near term recommendations, as well as our response to EPA's arguments for not implementing them previously in the oil and gas NSPS, and Section IV further discussion of our justifications for recommending a low discount rate of 0.7 percent.

II. Background on the SCC

The Interagency Working Group relied upon three climate economic models to estimate the SCC, called integrated assessment models (IAMs). IAMs, as suggested by their name, integrate climate science with economic analysis. Their overall architecture is relatively straightforward. First, they project future emissions based upon various socioeconomic (GDP and population) projections. Emissions are then translated into atmospheric concentration levels, concentration levels into temperature changes, and temperature changes into monetized economic damages. Damages increase over time as physical and economic systems become more stressed in response to greater climate change.

Comprehensively estimating the economic impacts from greenhouse gases is challenging, and the IAMs used to assess them systematically understate damages. Some of the most important effects (e.g. socio-economic conflict, collapsed ecosystems, cross-sectoral impacts,[2] etc.) have not been monetized in the economics literature, and these momentous potential consequences are simply excluded from the models. With climate science advancing very rapidly, and new findings typically projecting more severe impacts than previous ones, assumptions embedded in the models become quickly outdated. Finally, and perhaps most importantly, the models were not designed to handle the most complex and profound threat from climate change—potentially catastrophic and irreversible damages, affecting the entire world population and ecosystem for many generations to come.

Recognizing these shortcomings, the Interagency Working Group was careful to note in its first officially published SCC estimates (2010) that its calculations should not be viewed as a final product, but rather as a work in progress requiring regular revision. The Working Group also took an important first step toward incorporating catastrophic outcomes in the models, by employing the Monte Carlo methodology and using a fat-tailed probability distribution for climate sensitivity.[3] We commend the Working Group for this improvement.

Nevertheless, significant problems remain. The centuries-long impacts of greenhouse gases emitted today make the choice of the discount rate particularly contentious, because the farther into the future climate damages occur, the smaller the weight assigned to them as a result of discounting. Discounting at too great a rate could result in a heavy bias toward favoring the current generation and ignoring catastrophic damage several generations hence.

[2] Cross-sectoral impacts refer to interaction effects, where one type of climate damages can lead to or exacerbate another. For example, droughts or extreme weather events could lead to mass migration, and both of these to socio-economic conflict.

[3] A Monte Carlo will run an integrated assessment model thousands of times, each time randomly picking the value of uncertain parameters. In the case of the social cost of carbon, the Working Group ran 10,000 Monte Carlo simulations for each model, randomizing the value of climate sensitivity, the change in average global temperature associated with a doubling of CO2. For each randomly drawn climate sensitivity value, the integrated assessment model estimated the associated damages, with the final social cost of carbon estimate equaling the average value across all 10,000 runs, and then across all three models. A "fat-tailed" distribution refers to a distribution having a long extended "tail" at the upper end, as opposed to a normal bell curve. A fat-tailed climate sensitivity distribution specifies that temperature increases well above the "best guess/most likely" values are possible, while those below the best guess do not diverge too far from it.

Many of the problems associated with IAMs can be avoided, at least in theory, by using a "shadow price of carbon" (SPC) approach to assess climate change mitigation policies, which is distinctly different from cost-benefit analysis. Under the SPC approach, society determines a mitigation target based upon science and what it determines is a tolerable level of risk (rather than upon piecemeal marginal cost-benefit analysis regulation by regulation), estimates the marginal abatement cost of that target, and then pursues mitigation policies whose costs are less than or equal to that value – essentially a cost effectiveness framework. This approach more closely follows an insurance perspective than does the social cost of carbon approach – and is better suited for the kind of non-marginal changes in emissions that would be needed to achieve America's climate policy goals (rather than estimating the marginal damage of one extra ton of CO_2, the SPC is based upon a large change in emission levels and a defined target). But the SPC also has its drawbacks – the largest one being that politics rather than science could dominate the choice of the target, producing a target that falls short of what is needed to minimize catastrophic risks. Indeed, with Congress's failure to pass comprehensive climate legislation, the U.S. has not legally-binding target.

In this context, as long as the Clean Air Act is the vehicle for mitigation efforts, the cost-benefit approach used in regulatory impact analyses will take on greater significance. In turn, a sound social cost of carbon is needed to inform good policy. In this spirit, we submit these recommendations on the social cost of carbon for the power plant NSPS.

III. Recommendations that can be implemented for this rulemaking ("near term"):

1) <u>Finish reviewing the updated versions of the social cost of carbon models that were used for the 2010 estimates and re-estimate the SCC</u>. In the final oil and gas new source performance standards, the agency decided not to update the SCC with new versions of the models it used to estimate the SCC, noting that while updated versions were available, it needs to do additional analysis of them before using them for any rulemakings. The NSPS power plant proposal notes, however, that the Working Group set a preliminary goal of revisiting the SCC values within two years, or at such time as substantially updated models become available (p. 5-23 in proposed rulemaking, p. 3 in original SCC technical support document[4]). As of February 2012, that two year time frame has passed, and all three models used by the Working Group have been significantly revised. As such, unless the Agency can point to reasons why the updated models are inferior to the earlier versions, it should re-estimate them for this rulemaking. Improved estimates using the updated models would still be better than estimates derived from inferior versions.

2) <u>Use a lower interest rate to approximate the risk-free rate of return. We recommend 0.7 percent, the historical average return on 6 month U.S. Treasury Bills, for several reasons.</u> First, it is the closest proxy available for a risk-free rate of return. It is a better measure than what the Working Group chose, the long term yield on U.S. Treasury Notes, because these carry significantly more inflation risk than short term bills.[5] If the long term notes are a superior measure of the risk-free rate of

[4] Interagency Working Group on Social Cost of Carbon, with participation by Council of Economic Advisors, 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 Treasury (February 2010). Technical support document: social cost of carbon for regulatory impact analysis under Executive Order 12866. Docket ID EPA-HQ-OAR-2009-0472-114577.

[5] Mehra, Rajnish; Edward C. Prescott (2003). The Equity Premium Puzzle in Retrospect. In G.M. Constantinides, M. Harris and R. Stulz. Handbook of the Economics of Finance. Amsterdam: North Holland. pp. 889–938; Kocherlakota, Narayana R (1996). The

return despite their inflation risk than are the short term bills, EPA needs to explain why. It failed to do so in its response to NRDC's comments on the proposed oil and gas NSPS. Second, a low yield is consistent with assuming a low rate of time preference, adjusting for negative externalities, and adopting a risk management perspective over one of maximizing returns from mitigation investments. Section IV expands upon these three rationales supporting a lower discount rate. In responding to this recommendation, the Agency needs to explain why any criticisms it might have for using the yield on short term bills are sufficient to rule it out as valid discount rate over other rates that may have different drawbacks.

3) *At a minimum*, whatever discount rates EPA does adopt, it needs to include an estimate of the SCC using the government's own recommended lower bound sensitivity value for intergenerational discounting, of 1 percent (OMB, Circular A-4). The defense EPA provided for not doing this in its response to comments on the proposed oil and gas NSPS, that two of the three discount rates it used (2.5 percent and 3 percent) fell within the inter-generational range specified by OMB (1 to 3 percent), is inadequate on at least two grounds. First, it is inconsistent with how *intra*-generational costs and benefits are discounted in regulatory impact analyses: agencies routinely use OMB's *full* range of intra-generational discount rates when valuing intra-generational costs and benefits, of 3 to 7 percent.[6] Second, it is misleading to argue that two of the three rates the agency used are within the inter-generational range. This suggests the agency was balanced its treatment of inter-generational discount rates, when in fact it chose values from the upper end of the range. This has significant implications for the benefits analysis: at 2.5 and 3 percent, carbon damages from a new natural gas combined cycle plant in 2020 are 1.6 and 1 cents per KWh, respectively, versus 11.3 cents using a 1 percent discount rate.[7] For a new conventional coal plant in 2020, the corresponding figures are 3.4 and 2.1 cents per KWh, versus 21.4 cents.[8]

4) If the agency is going to base its lower bound discount rate on a declining rate, as it did by using the Newell-Pizer rate, it should consider *all* available estimates of declining rates. EPA's reasoning for not doing so in the oil and gas NSPS, that it was studying the emerging literature on declining discount rates, does not provide a rationale for its choice: in selecting the Newell-Pizer rate,[9] the Agency effectively acknowledged declining discount rates as an accepted methodology in

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Equity Premium: It's Still a Puzzle. Journal of Economic Literature 34 (1): 42–71. http://www.econ.ucdavis.edu/faculty/kdsalyer/LECTURES/Ecn200e/Kocherla.pdf.

[6] Typically costs and benefits are estimated using 3 and 7 percent discount rates, where the 7 percent rate is an estimate of the average before-tax rate of return to private capital in the U.S. economy. In the case of the SCC, the Interagency Working Group suggests a corresponding range of 3 to 5 percent rather than 3 to 7 percent, due to its determination that climate damages are likely to affect primarily consumption rather than investment flows. As OMB notes: "The effects of regulation do not always fall exclusively or primarily on the allocation of capital. When regulation primarily and directly affects private consumption (e.g., through higher consumer prices for goods and services), a lower discount rate is appropriate." Specifically, a rate that discounts future consumption (rather than investment) flows to their present value is prescribed. The Working Group estimated the upper end value for this rate at 5 percent, the post-tax return to households on risky investments.

[7] The 1 percent SCC estimates were taken from Johnson and Hope (forthcoming, 2012), who re-estimated the Working Group's models at lower discount rates for 2012. Johnson, LT, and Hope, C (forthcoming September 2012). The social cost of carbon in U.S. regulatory impact analyses: An introduction and critique. Journal of Environmental Studies and Sciences 2(3).

[8] Each calculation was derived as follows: $ damages/KWh = (total annual tons of emissions for unit type * SCC/ton CO2)/total number of annual kilowatt hours for assumed 600 MW power plant operating at an 85% capacity factor. The 2.5, 3, and 5 percent SCCs, plus the 95th percentile SCC at 3 percent, were taken from the proposed NSPS power plant RIA for the 2020 SCC values. For the 1 percent discount rate SCCs, we used 2010 estimates from Johnson and Hope (see previous footnote), as they did not estimate future SCC values. Our 1 percent SCC estimates are therefore conservative, as the SCC grows over time.

[9] Newell, R., and W. Pizer. 2003. Discounting the distant future: how much do uncertain rates increase valuations? Journal of Environmental Economics and Management 46: 52-71.

economics. Having made that choice, the Agency needs to explain why the Newell-Pizer rate is a superior measure to two other available estimates it did not use, the UK Green Book and Weitzman declining discount rate schedules.[10] Specifically, it needs to show why the Newell-Pizer rate is superior to these alternatives, after enumerating the strengths and shortcomings of all three alternatives.

5) <u>A 5 percent discount rate should not be used, nor any other rate that reflects a societal goal of maximizing market returns rather than minimizing climate damages. Actions such as climate mitigation that yield precautionary benefits should be discounted a rate no higher than the risk-free rate, because the risk premium is negative for precautionary investments</u>. EPA argues that a 5 percent rate is used to allow for the possibility that climate mitigation could be correlated with baseline consumption levels, i.e. the benefits of reducing emissions happen to be low in those states of the world in which baseline consumption is also low. In this instance, having invested in mitigation would increase the overall risks pertaining to future welfare, justifying a higher discount rate. We disagree with this justification because the downside risks of alternative investments to mitigation (i.e. larger than expected losses, due to large climate damages) are much higher than the upside risks from such investments (i.e. higher than expected returns, due to low climate damages). Section IV provides further discussion.

6) <u>Include an estimate of benefits using the 99th percentile SCC value</u>. EPA rejected our recommendation to use the 99th percentile in the final oil and gas NSPS, noting that the appropriate place for such "detailed technical information" was in the Working Group's technical support document (TSD) for the SCC estimates. We strongly reject this: while presentation of the *full* distribution of SCC estimates may belong in the TSD, the 99th percentile SCC is not just one point of many along a continuous distribution. Rather, as the "worse-case" outcome produced by the models, it is a critical value in assessing climate damages: risk aversion to catastrophic outcomes is widely acknowledged as an essential component to how people value climate mitigation efforts. Moreover, as EPA notes in its response to comments, "the estimates do not include all significant climate changes damages and are therefore underestimates." The Agency has not sufficiently defended its position that the 95th percentile better captures risk aversion or a complete representation of damages than the 99th percentile. In the absence of such a justification, the 99th percentile illustrative benefits need to be calculated and presented within the proposed rulemaking. This has significant implications for the benefits analysis: at the 95th percentile (3 percent discount rate), carbon damages from a new natural gas combined cycle plant in 2020 are 3.1 cents per KWh, versus 5.1 cents at the 99th percentile (3 percent discount rate).[11] For a new conventional coal plant in 2020, the corresponding figures are 6.5 cents per KWh, versus 10.8 cents. Using the 99th percentile value at a 1 percent discount rate (see Recommendation #3 above), carbon pollution damages for a natural gas plant are 68 cents per KWh, and 143 cents per KWh for coal.

7) <u>Provide a more transparent presentation of the SCC, such that it better conveys the limitations of the models in comprehensively capturing climate damages and catastrophic risks</u>. We recommend including in a support document to the RIA a detailed account of damages included and excluded from the models in tabular format, accompanied by qualifying text as needed. EPA rejected this

[10] For Weitzman and Green Book references and discount rate schedules, see attachment (NRDC comments submitted to the proposed oil and gas industry new source performance standards).
[11] The 99th percentile SCC estimates were taken from Johnson and Hope (forthcoming, 2012—see footnote 5) and were 2012 rather than 2020 values; calculations were based upon the formula given in footnote 6 above.

suggestion from NRDC in the final oil and gas industry NSPS on insufficient grounds, noting that the complexities and ambiguities in the models do not lend themselves to the suggested tabular format. This is a poor justification: despite the difficulties, it is incumbent upon the Agency to develop a methodology to clearly explain more precisely what is and is not in each model, so that readers know the bases of the damage estimates contained therein. The discussion of each model in the SCC technical support document, while it gives some detail, remains too general. While it may not be possible to develop one table for each model (as was initially recommended) of included versus excluded damages, the Agency could work toward developing a set of tables for each model designed to handle their complexity. For example, an overview table for each model might list individual studies embedded in the model. Columns might include impact (e.g. agricultural damages; sea level rise), metric (e.g. agricultural yield lost per observed deviation in climatic variable in X geographical area; property values of submerged structures resulting from sea level rise of X inches in Y geographic zone), and the relevant citations. Another table might list aggregated damage functions within the given model (e.g. all sea level rise impacts; all agricultural impacts), and the underlying papers that form the bases of each, with reference to the citations in the supporting literature overview table. A third table could provide a list of damages for which there are studies with monetized damage estimates that were not used (with information provided similar to that in the overview table). Finally, a global table that applies to all three models could be provided that lists damages for which no underlying studies exist to be able to use in any of the models (e.g. socio-economic conflicts arising from climatic stresses). Whatever the tables are not able to adequately or fully capture could be addressed in supplementary text and footnotes. We do not believe these would be so numerous as to make the exercise impractical, but if EPA finds this to be the case, it needs to work to solve it rather than abandon the exercise altogether.

IV. Expansion of arguments for 0.7 percent discount rate recommendation

This section briefly expands upon the reasons provided in Recommendation #2 for adopting a discount rate of 0.7 percent: its low value is consistent with 1) assuming a low rate of time preference; 2) a return adjusted for negative externalities; and 3) adopting a risk management perspective over one of maximizing returns mitigation investments.

1) Time preference

Embedded in market interest rates is what economists call a “pure rate of time preference,” or what one might term impatience. Individuals have a preference for consumption today over consumption in the future. In terms of interest rates, a positive rate of time preference results in lenders requiring compensation (interest) for delaying the use of their money.

Discounting costs and benefits based upon time preference is highly problematic when they occur over multiple generations, as is the case with climate change. To the extent that a positive rate of time preference is embedded in the discount rate used for the SCC, a greater value is assigned to damages occurring closer in time than those farther out. Costs of mitigation are similarly assigned a higher value the sooner they are incurred in time. Because the costs of mitigation tend to be up-front, and the damages such mitigation prevents farther in the future, discounting tilts the benefit-cost ratio in favor of less mitigation and the current generation on both the cost and benefit sides.

Many argue that only a value of zero for time preference makes sense in the context of climate change. As OMB Circular A-4 notes, “Although most people demonstrate time preference in their own consumption behavior, it may not be appropriate for society to demonstrate a similar preference when deciding between the well-being of current and future generations. Future citizens who are affected by such choices cannot take part in making them, and today's society must act with some consideration of their interest." (OMB Circular A-4, p.35).

Adjusting market interest rates to remove the time preference component embedded lowers the discount rate. The number is not small: evidence suggests a central time preference estimate of approximately 1.5 percent;[12] some papers use values as high as 3% and 4%.[13,14]

2) Adjusting the discount rate for negative externalities

Another reason for using a discount rate lower than observed market interest rates is that they do not take into account many things that decrease real output, such as depreciation of natural capital (e.g., loss of natural habitats to development) and pollution externalities (e.g., non-CO2 pollutants from burning fossil fuels.[15]

We can get a sense of the distortion in market interest rates caused by negative externalities by examining past efforts made to adjust gross domestic product (GDP) for them. Estimates vary widely, depending upon the year(s) examined and the methodologies employed, but all find adjusted growth to be lower than unadjusted. Goodstein (2004) summarizes three studies of adjusted annual GDP per capita growth, finding a range of .2 to 3.1 percentage points lower, for various time periods.[16,17,18,19] A more recent analysis by Talberth et al. (2007)[20] found annual per capita adjusted growth rate 2.5 percentage points below GDP. This data suggests that, based upon historical data alone (which may be more forgiving than the future under climate change), adjusting market interest rates for negative externalities significantly lowers the discount rate and in some instances could even imply negative discount rates.

3) Risk management: discounting framework versus an insurance framework

[12] Her Majesty's Treasury (2003). The Green Book: Appraisal and Evaluation in Central Government, Treasury Guidance. Nordhaus (2011) uses 1.5% as a default value in a recent analysis. Nordhaus, W (2011). Estimates of the social cost of carbon: background and results from the RICE-2011 model. Cowles Foundation Discussion Paper No. 1826.

[13] Rates of time preference are estimated in numerous contexts, not just in asset markets. As such, some estimates can be higher than observed market interest rates.

[14] The Stern Review used a rate of pure time preference of 0.1 percent per year, based on an arbitrary estimate of the annual probability that the human race will not survive (though it adopted the view that damages in the future should not be discounted on the basis of the current generation preferring to consume now at the expense of future generations). Stern, N (2007). The Stern Review; The Economics of Climate Change. Cambridge, UK: Cambridge University Press, available online at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

[15] GDP also excludes things that increase welfare, such as any household labor that is not bought and sold in the market. On net, however, it excludes significantly more "bad" things than "good" things.

[16] Goodstein summarizes Nordhaus and Tobin (1972), who estimate a .7 percentage point difference in annual per capita growth between 1929-1965, and a 1.8 percentage point difference between 1947-1965; Zolatas (1981), who estimates 1.8 (1947-1965), 1.6 (1950-1965), and 1.5 percent (1965-1977) differences; and Daly and Cobb (1989), who estimate differences of .2 (1950-1960), .6 (1960-1970), 3 (1970-1980) and 3.1 (1980-1986).

[17] Nordhaus W and Tobin J (1972). Is growth obsolete? In Economic Research: Retrospect and Prospect Vol 5: Economic Growth, National Bureau of Economic Research.

[18] Zolatas X. (1981). Economic Growth and Declining Social Welfare. New York: New York University Press.

[19] Daly H, and Cobb J (1989). For the Common Good. Boston: Beacon Press.

[20] Talberth J, Cobb J, and Slattery N (2007). The genuine progress indicator 2006: a tool for sustainable development. Redefining Progress. Oakland: CA.

Using market interest rates as discount rates assumes that investors in a market for mitigation, were it possible for one to exist,[21] would require similar returns and risk levels as those observed in asset markets today. This assumption is wrong on several counts.

First, basing climate change discount rates upon observed markets cannot possibly be correct: the worst-case scenario when investing in regular asset markets is that an individual loses all of his or her life savings. This is hardly comparable to the kinds of catastrophic societal risks possible from climate change.

Second, theoretically, mitigation investments are more appropriately viewed as an insurance problem, not a profit-maximizing venture. Mitigation is a precautionary investment, and precautionary investments yield their highest returns in "bad" states of nature, not when asset markets are at their peak.

These two factors point to adding a negative risk premium to any descriptive discount rate, with a correspondingly a higher weighting of losses.[22] The negative "returns" individuals are willing to pay for in insurance markets, as evidenced by actuarial data, provide an example: purchasers pay to insure themselves against very bad outcomes that may never happen.

Unfortunately, the insurance analogy understates the case. With standard insurance policies:

a) Damages are often fully recoverable (i.e. not irreversible), examples being property damages resulting from fires or automobile accidents.[23]

b) The probabilities of bad outcomes generally are known. These are not known in climate change, and people are more averse to investing in risky assets if the potential losses and the probability of those losses are uncertain (Gollier, 2009).[24] This is called "ambiguity aversion" in the literature. Gollier shows that under certain plausible conditions,[25] aversion to ambiguity will decrease the discount rate, and could do so quite substantially.

c) The probabilities of catastrophic outcomes in climate change are higher than those observed in insurance markets.

Given negative discount rates implied by an insurance approach do not lead to sensible policy conclusions in cost-benefit analysis (cost-benefit analysis is based upon marginal changes rather than

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[21] A "mitigation investment" would be any action whose purpose is to reduce climate change impacts by reducing greenhouse gas emissions. A market for such investments could not exist, however, because mitigation is a public good: any individual's investment, by itself, would not impact climate change, so there would be no incentive to make such investments. In addition, any benefits resulting from an individual's investment benefit everyone, regardless of whether they contribute to the investment or not, creating a "free-rider" problem and underinvestment. As a public good, mitigation must be invested in collectively at a large scale.

[22] Cochran, JH (2001). Asset Pricing. Princeton: Princeton University Press.

[23] Minus any deductibles.

[24] Gollier, C (2009). Portfolio choices and asset prices: The comparative statics of ambiguity aversion. Toulouse School of Economics (LERNA and IDEI) working paper.

[25] These conditions are: 1) as income rises, a person is more willing to increase investments in assets that are risky, whose risk level and size of potential loss is known; and 2) as income rises, a person is more willing to invest in assets with uncertain losses and uncertain probabilities of such losses.

the non-linear catastrophes of the kind associated with negative discount rates), we view a 0.7 percent discount rate as a middle ground.

Attachment

NRDC comments on proposed oil and gas industry new source performance standards

Comments on the Social Benefits of Methane Reductions from the Proposed Oil and Gas New Source Performance Standards

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November 17, 2011

Preface

In the Regulatory Impact Assessment accompanying the proposed oil and gas rules, EPA estimated the social benefits of methane reductions —a monetized value of the marginal benefit of reducing methane's impact on climate change—by applying the 100 year global warming potential (GWP) to the social cost of carbon (SCC) as estimated by the Obama Administration's Interagency Working Group on the Social Cost of Carbon (February 2010). The agency used the 100 year GWP given in the IPCC's Second Assessment Report, equal to 21 (a GWP of 21 states that a ton of methane has 21 times the radiative forcing of a ton of CO_2).

After estimating these monetized methane reduction benefits, EPA then elected not to use them in its formal cost-benefit assessment, on the rationale that there are significant uncertainties with the GWP methodology. The agency also noted that efforts to estimate methane reduction benefits directly (i.e., not using GWPs) were problematic and not ready for use.

Our concerns with EPA's overall choice not to include monetized methane benefits in its RIA are taken up in our main comments on the rule. The purpose of this report is to highlight several other important modifications in both the GWP method (if EPA decides to use this approach) and the SCC method (regardless of which method EPA chooses) that are necessary to fully capture the social benefits of methane reduction. Several of these measures EPA can and should implement for this rulemaking. Others we suggest EPA recommend to the Working Group in its next SCC revision.

Introduction

Estimating economic impacts from greenhouse gases is challenging, causing the integrated assessment models (IAMs) used to assess them to systematically understate damages. Some of the most important effects (e.g. socio-economic conflict, collapsed ecosystems, cross-sectoral impacts,[1] etc.) have not been monetized in the economics literature, resulting in their being excluded from the models. With climate science advancing very rapidly, and new findings typically projecting more severe impacts than previous ones, assumptions embedded in the models become quickly outdated. Finally, and perhaps most importantly, the models were not designed to handle the most complex and profound threat from climate change—potentially catastrophic and irreversible damages, affecting the entire world population and ecosystem for many generations to come.

Recognizing these shortcomings, the Interagency Working Group was careful to note in its first officially published SCC estimates (2010) that its calculations should not be viewed as a final

[1] Cross-sectoral impacts refer to interaction effects, where one type of climate damages can lead to or exacerbate another. For example, droughts or extreme weather events could lead to mass migration, and both of these to socio-economic conflict.

product, but rather a work in progress requiring regular revision. The Working Group also took an important first step toward incorporating catastrophic outcomes in the models, by employing the Monte Carlo methodology and using a fat-tailed probability distribution for climate sensitivity.[2] We commend the Working Group for this improvement.

Nevertheless, significant problems remain. The centuries-long impacts of greenhouse gases emitted today make the choice of the discount rate particularly contentious, because the farther into the future climate damages occur, the smaller the weight assigned to them as a result of discounting. Discounting at too great a rate could result in a heavy bias toward favoring the current generation and ignoring catastrophic damage several generations hence. Greenhouse gas emissions also affect the entire earth's atmosphere regardless of where the emissions occur. A perverse consequence of this is that many of the world's poor, who neither emitted the gases nor benefited from the economic growth that ensued, will be disproportionately impacted. This makes decisions about "equity weighting" important and controversial.[3]

Many of the problems associated with IAMs can be avoided, at least in theory, by using a "shadow price of carbon" (SPC) approach to assess climate change mitigation policies, which is distinctly different from cost benefit analysis. Under the SPC approach, society determines a mitigation target based upon science (rather than upon piecemeal marginal cost benefit analysis regulation by regulation), estimates the marginal abatement cost of that target, and then pursues mitigation policies whose costs are less than or equal to that value—essentially a cost effectiveness framework. This approach more closely follows an insurance perspective than does the social cost of carbon approach—and is better suited for the kind of non-marginal changes in emissions that would be prescribed by comprehensive climate legislation we support (rather than estimating the marginal damage of one extra ton of CO_2, the SPC is based upon a large change in emission levels and a defined target). But the SPC also has its drawbacks—the largest one being that politics rather than science could dominate the choice of the target, producing a target that falls short of what is needed to minimize catastrophic risks. Indeed, with Congress's failure to pass comprehensive climate legislation, the U.S. effectively has no target.

[2] A Monte Carlo will run an integrated assessment model thousands of times, each time randomly picking the value of uncertain parameters. In the case of the social cost of carbon, the Working Group ran 10,000 Monte Carlo simulations for each model, randomizing the value of climate sensitivity, the change in average global temperature associated with a doubling of CO_2. For each randomly drawn climate sensitivity value, the integrated assessment model estimated the associated damages, with the final social cost of carbon estimate equaling the average value across all 10,000 runs, and then across all three models. A"fat-tailed" distribution refers to a distribution having a long extended "tail" at the upper end, as opposed to a normal bell curve. A fat tailed climate sensitivity distribution specifies that temperature increases well above the "best guess/most likely" values are possible, while those below the best guess do not diverge too far from it.

[3] Equity weighting refers to weighing damages to poor countries more heavily than those to wealthy countries in any given time period. This is distinct from weighting damages over time. To the extent that developing countries become wealthier in the future from current high emission levels (e.g. China), the resulting growth in income over time is partially canceled out by discounting damages. More precisely, the more a country's income is assumed to grow (which increases with increasing emission levels), the lower the present value of climate damages. In this sense, discounting "equity weighs" damages over time by counting damages to richer future generations less the richer they become (See Section II.a).

In this context, as long as the Clean Air Act is the vehicle for mitigation efforts, the cost benefit approach used in regulatory impact analyses will take on greater significance. In turn, a sound social cost of carbon is needed to inform good policy. We therefore focus these comments on the social cost of carbon, its revision, and its application using methane global warming potentials (GWPs) in this rulemaking.

Our recommendations regarding the GWP method and SCC are summarized as follows:

1) ***Methane GWP***. EPA should use the 100 year GWP estimate from the IPCC's Fourth Assessment Report, of 25, rather than the 21 estimate from the Second Assessment Report (Recommendation #1). In addition, EPA should do a sensitivity analysis using the most recently published GWP estimate of 33 (Shindel et al.) (Recommendation #2).

2) ***Improved SCC***. Regardless of whether EPA uses the GWP or SCM[4] method, the agency should estimate an improved social cost of carbon, making the following changes[5]:

   a. Use the updated versions of the social cost of carbon models that were used for the 2010 estimates (Recommendation #3).
   b. Reduce CO2 fertilization benefits to reflect methane's actual contribution of CO2 to the atmosphere (Recommendation #4).
   c. Use a lower discount rate. We recommend .7%, the average return on 6 month U.S. Treasury Notes. We consider this a better measure of the risk-free rate of return than the yield on long-term U.S. Treasury Bonds (which carry inflation risk), the rate chosen by the Working Group. (Recommendation #5). *At a minimum*, **whatever discount rates EPA does adopt, it needs to include an estimate of the SCC using the government's <u>own</u> recommended lower bound sensitivity value for intergenerational discounting, of 1% (OMB, Circular A-4).** The choice by the Working Group not to use the lower bound was not justified, and should not be repeated here. If EPA elects not implement this recommendation, we request it provide a justification (Recommendation #6).
   d. Short of our preferred.7% rate, but better than the current set used by the Working Group, use a set of discount rates that take into account long run uncertainty in interest rates. The range should include Weitzman[6] and UK Greenbook[7] declining discount rate schedules, in addition to the Newell-Pizer estimate (Recommendation #7).

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[4] Because the social cost of carbon models serve as the underlying structure from which direct models (for other gases) are being built, these recommendations apply regardless of which method EPA uses.
[5] As noted in our main comments, nothing prevents EPA from using an updated and improved method while waiting for the next official revision by the Interagency Working Group.
[6] Weitzman, M (2001). Gamma Discounting. American Economic Review, American Economic Association, vol. 91(1): 260-271.
[7] Lowe, J (2008). Intergenerational wealth transfers and social discounting: supplementary greenbook guidance. UK Treasury. http://www.hm-treasury.gov.uk/d/4(5).pdf. Note that the schedule in this supplement to the greenbook subtracts out an implicit positive value for the pure rate of time preference, appropriate for intergenerational discounting.

3) ***Transparency of SCC***. EPA should provide a more transparent presentation of the social cost of carbon used in the calculations, such that it better conveys the limitations of the models to handle catastrophic risks and many damage categories, by

    a. Providing a detailed list of damages included and excluded from the models in tabular format (Recommendation #8).
    b. Providing the 99th percentile social cost of carbon estimates (Recommendation #9).

4) ***Recommendations for the Interagency Working Group***. EPA should recommend to the Interagency Working Group, along with Recommendations 3-9 above, that the Group:

    a. Incorporate risk aversion according to different available methodologies as summarized in Kosky and Kopp (2011)[8] (Recommendation #10).
    b. In addition to incorporating risk aversion, better integrate the very high and catastrophic damages to which individuals are risk averse into all three models. Specifically, the Working Group should use Weitzman's analysis (2009)[9] to "extend the grid" in the Monte Carlo simulations; for catastrophic outcomes, value damages at Weitzman's implied "value of statistical life on Earth as we know it," the VSL (value-of-a-statistical life) multiplied by world population; reduce the amount of low cost adaptation assumed in the models; and modify damage functions to reflect cross-sectoral damages (Recommendations #11, 12, 13, 14).
    c. Conduct sensitivity analyses equity weighting the SCC according to different available methods (Recommendations #15, 16).
    d. Review the literature for estimates of the ratio between non-use and use values, and develop a methodology to apply a multiplication factor (or factors) to relevant use values included in the models (Recommendation #17).
    e. Dedicate full time staff to collecting and reviewing new climate science and economic modeling on an ongoing basis, and regularly incorporate these developments into the SCC models. As they become available, post findings on a public website with links to sources (Recommendations #18, 19).
    f. Update the models to reflect recent research on agricultural changes, which suggest the CO2 fertilization is overestimated in the FUND model, and that much, if not all, fertilization benefits may be cancelled out by negative impacts on agriculture (e.g. extreme heat, pests, and weeds) (Recommendation #20).
    g. Examine whether the upper ends of the 612 to 889 ppm of CO2 in the four business-as-usual scenarios used by the Working Group reflect current worse-case estimates (Recommendation #21).

[8] Kousky, C, and Kopp, RE (2011). Risk Premia and the Social Cost of Carbon: A Review. Economics: The Open-Access, Open-Assessment E-Journal. Discussion Paper No. 2011-19. http://www.economics-ejournal.org/economics/discussionpapers/2011-19.
[9] Weitzman, M (2009). On Modeling and Interpreting the Economics of Catastrophic Climate Change. Review of Economics and Statistics 9(1): 1-19.

Section I below provides a more detailed summary discussion of these comments and recommendations, while Sections II and III provide extended discussions of discounting and equity weighting, and catastrophic risk representation in Monte Carlo analysis, respectively.

I. Discussion of NRDC Concerns and Recommendations

1. ***Methane GWP***. If EPA uses the GWP method, it should use more appropriate values for methane's GWP.

   <u>Recommendation #1:</u>
   Use the IPCC's most recent (Fourth Assessment Report) 100 year global warming potential for methane of 25.

   <u>Recommendation #2:</u>
   Do a sensitivity analysis using the Shindel et al. GWP estimate of 33.

   <u>Discussion</u>. *EPA used the IPCC's Second Assessment Report (2001)[10] 100 year global warming potential for methane of 21, but a more current IPCC estimate is available from the Fourth Assessment Report, 2007[11], of 25. There is also an estimate that improves upon the IPCC's by taking into account positive feedback loops (e.g. methane causing warming which then causes permafrost to melt, releasing yet more methane), provided by Shindell et al. (2009), of 33. As set forth in our main comments, maintaining consistency with inventory reporting is irrelevant to EPA's estimation of the social benefits from methane reductions associated with the proposed rule.*

2. ***Improved SCC***. Regardless of whether EPA uses the GWP or SCM method, the agency should re-estimate the social cost of carbon in a number of ways accounting for updates and improvements. The three models used for the 2010 estimates of the social cost of carbon are all outdated. Revised versions partially incorporating new science are available for each of the three models. Separately, CO2 fertilization benefits will be significantly overestimated in a methane GWP due to the way in which methane decomposes into CO2. Finally, the discount rates used were too high, in that (1) they did not take into account aversion to catastrophic risk or externalities not internalized to market production; and (2) only one (Newell-Pizer) of three (Newell-Pizer, Weitzman, UK Greenbook) well-established declining discount rate schedules was chosen, without adequate justification.

   While we recognize that some of these problems will need to be addressed more fully in the Working Group's next social cost of carbon revision, EPA can make interim adjustments for this rulemaking.

   <u>Recommendation #3:</u>
   At minimum, estimate an interim updated SCC value using the revised versions of the SCC models, rather than the versions used in the 2010 estimates. These versions are ready for use, and we are not aware of any reason this cannot be done in time for this rulemaking. If EPA elects not to do so, we request a justification.

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[10] Intergovernmental Panel on Climate Change (IPCC), IPPC Second Assessment Report Climate Change 1996.
[11] Intergovernmental Panel on Climate Change (IPCC), IPPC Fourth Assessment Report Climate Change 2007.

<u>Recommendation #4:</u>
Reduce CO2 fertilization benefits in the FUND model in proportion to methane's decomposition into CO2 before being re-run. If it is not possible to structurally adjust the fertilization levels within the time frame of the ruling, EPA should either a) estimate the CO2 fertilization effect separately, and subtract its value accordingly from the SCC. Ackerman and Munitz (2011)[12] provide an example of how to do this with the FUND model; or b) exclude FUND from the SCC estimates used to calculate methane reduction benefits.

<u>Discussion</u>. Methane emissions decompose into much smaller amounts of CO2 than implied by the GWP calculation. Specifically, methane decomposes to CO2 on a molecule for molecule basis, with one ton of methane converting into 2.75 tons of CO2 (which is the ratio of the molecular weights). Thus, it would be wrong to include CO2 fertilization in the models in proportion to GWP equivalencies, because doing so incorrectly assumes that one ton of methane gives 25 (or 33, using Shindell et al.*'s estimate) times the fertilization benefits as a ton of CO2. This error is particularly significant in the FUND model, creating a large distortion that cannot be ignored: CO2 fertilization benefits are so high in FUND that they lead to a negative SCC (i.e. net benefits from climate change) at the 5% discount rate. They also significantly lower the (positive) SCC values estimated at the 2.5% and 3% rates.*

<u>Recommendation #5:</u> As a middle ground, use a discount rate of .7%, the long run average yield on 6 month U.S. Treasury Notes. This is a better measure of a risk-free asset than the long term yield on U.S. Treasury Bonds used by the Working Group, because it carries much less inflation risk. The alternative would be to revise the integrated assessment models to adjust for risk and ambiguity aversion to catastrophic impacts, whether through re-estimating discount rates or through other methods (Kousky and Kopp, 2011[13]), as well as for negative externalities. But this would be very difficult and time consuming, and certainly not feasible within the time frame of this rulemaking. We think .7% is therefore a reasonable and practical rate. It is conservative in that it does not prescribe mitigation investments with returns comparable to those found in insurance markets (i.e. negative expected returns), and still allows for a low, but still positive, level of real (i.e. .7% assumes there is real growth despite negative externalities embedded in growth rates—see Section II.e) economic growth.

<u>Discussion</u>. In its 2010 social cost of carbon estimates, the Interagency Working Group chose discount rates based upon observed market interest rates, after concluding that climate mitigation was best viewed as affecting private consumption rather than investment decisions.[14] Because these rates "describe" what occurs in actual markets,

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[12] Ackerman, F and Munitz, C (2011). Climate damages in the FUND model: A disaggregated analysis SEI Working Paper WP-US-1105.

[13] Kousky, C, and Kopp, RE (2011). Risk Premia and the Social Cost of Carbon: A Review. Economics: The Open-Access, Open-Assessment E-Journal. Discussion Paper No. 2011-19. http://www.economics-ejournal.org/economics/discussionpapers/2011-19.

[14] OMB Circular 4 specifies appropriate discount rates based upon whether they primarily affect consumption versus investment streams. If mitigation displaces consumption, OMB specifies an upper bound of 5% (what consumers

the framework they represent is called "descriptive." The Administration chose this approach over the Ramsey "social" discounting approach (see Section II.a) which, while sometimes referred to as a "prescriptive" approach (discounting based upon normatively selected parameters), is actually a combination of the two. For example, the Ramsey formulation requires assumptions about actual economic growth rates in the future, which are based upon observed historical rates (thus descriptive); it also requires assumptions about how damages should be weighted according to income levels (thus "normative" or "prescriptive").

The Working Group concluded that, because there was wide disagreement over normative parameters in the Ramsey discount rate, using market discount rates would be "the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance." With respect to theoretical foundations, the Working Group refers to the "Kaldor-Hicks" (KH) compensation test, which states that if the gains of a policy exceed the losses then it is possible for winners to compensate losers. Mathematically, there is a net gain in social welfare regardless of how costs and benefits are distributed.

We disagree with this conclusion, for a number of reasons. First, the KH criteria does not require actual compensation to occur—even if income growth exceeds damages caused by climate change, those harmed by such damages will not necessarily be compensated. Second, the interest rate proxies chosen by the Administration (5%, the average post-tax return on risky assets; 3%, the average post-tax return on long term U.S. Treasury Bonds and consistent with OMB's lower bound recommended consumption interest rate for <u>intra</u>-generational discounting; and 2.5%, to capture long term uncertainty in interest rates), are <u>not</u> consistent with contemporary economic theory <u>in the context of climate change</u>. Specifically, they:
(1) place more weight on the current generation over future generations, simply because they happened to be born first (this is described as having a preference for consumption today over delaying it into the future, or the "pure rate of time preference" (see Section II.c). This does not maximize social welfare across multiple generations.
(2) treat mitigation as a problem of maximizing market returns, rather than as an insurance problem, where the goal is to instead minimize catastrophic risk (i.e. they do not account for risk or ambiguity aversion[15]—both central to climate change; see Section II.d).
(3) fail to internalize negative externalities associated with market production—an issue identified in every introductory economics textbook (see Section II.e).

These problems being noted, the insurance framework we support corresponds to a negative discount rate, because expected returns on insurance policies are negative—

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require in returns from risky assets); if it displaces investment, OMB specifies an upper bound of 7%, the rate of return on capital investments).

[15] Ambiguity aversion refers to aversion to not knowing what the actual probability distributions are of different possible outcomes, while risk aversion refers to aversion to catastrophic losses with known probabilities. See Section II for further discussion.

policy holders pay more in premiums than insurance companies pay out to cover losses (i.e., any individual's expected return on an insurance policy is negative). But, in the context of cost-benefit analysis, which is based upon marginal changes rather than non-linear catastrophes, negative discount rates are not applicable.

Recommendation #6:

Whatever discount rates are adopted, at a minimum include, in the range, the U.S. government's own recommended lower bound sensitivity value for intergenerational discounting of 1% (OMB, Circular A-4). If EPA elects not implement this recommendation, we request that it provide a justification.

Discussion. *For its "uncertainty discount rate," the Administration selected 2.5%, derived from Newell and Pizer's estimated declining discount rate schedule (2003).*[16] *It ignored the schedule estimated by Weitzman (2001), which prescribes more conservative (lower) rates, as well as the schedule specified in the UK's Greenbook guidelines with a zero rate of time preference (see Section II.c), also lower.*[17] *The Administration's argumentation suggests it would reject Weitzman's values because they are based upon survey data rather than real markets. This reasoning would be flawed, however: the Newell-Pizer rates are based upon observations of interest rates in a world without climate change—we have no way of knowing what rates will be with increasing climate disruption. It that sense, one could argue that Newell-Pizer's data is also hypothetical, and Weitzman's perhaps better: he surveyed 2,800 Ph.D. economists and asked them what discount rates they thought should be used for climate change analysis. The percentage of surveys returned was excellent (77%), and his results published in the top economics journal in the profession. Notably, the top 50 preeminent scholars in his sample (the "blue ribbon" economists) prescribed rates comparable to the other respondents.*

Recommendation #7:

Short of our preferred .7% rate, but better than the current set used by Working Group, use a set of discount rates that take into account long run uncertainty in interest rates. The range should include Weitzman, and the UK Greenbook (zero time preference), declining discount rate schedules (see Section II.c), in addition to the Newell-Pizer estimate. If EPA elects not to do so, we request a justification**.**

[16] Newell, R., and W. Pizer. 2003. Discounting the distant future: how much do uncertain rates increase valuations? Journal of Environmental Economics and Management 46: 52-71.

[17] The UK zero time preference schedule (Lowe, 2008) is as follows:

	0-30 years	31-75 years	76-125 years	126-200 years	201-300 years	301+ years
UK Treasury discount rate schedule, zero rate of time preference	3.00%	2.57%	2.14%	1.71%	1.29%	.86%

Notes: *Stern Review* used a discount rate of 1.4%.

The Weitzman (2009) schedule is as follows:

	1-5 years	6-25 years	26-75 years	76-300 years	300+ years
Weitzman schedule	4%	3%	2%	1%	0%

3. ***Transparency of SCC.*** The proposed rulemaking does not present the SCC calculation transparently. The omissions result in a failure to at least partially convey catastrophic risks, and how high damages might ultimately be.[18]

Recommendation #8:
Identify what damages are included (and not included), for each model, and present them in detailed tables in the main body of the text. We are not aware of any reason this cannot be done in time for this rulemaking.

Discussion. In its comments on the 2010 GHG and CAFE standards rulemaking, NRDC requested that the Working Group present, in tabular form, a list of included and excluded damages in each model in its publication of the 2010 social cost of carbon estimates. The publication did not include this information, without any justification offered by the Group.

Recommendation #9:
Present 99th percentile estimates in the main body of the text, and include them for sensitivity analysis (the Working Group relegated these to an appendix in its 2010 SCC estimates). In so doing, EPA should note that the 99th percentile itself is likely an understatement of worse-case outcomes, and should therefore not be considered representative of them. We are not aware of any reason this cannot be done in time for this rulemaking.

Discussion. The Administration made a significant improvement in its first official SCC estimates in February 2010 by reporting the 95th percentile values as one of the main sensitivity results. However, given the strong aversion people have to catastrophic and irreversible risk, and the models' systematic biases downward due to missing damages, the 99th percentile represents a more accurate (if still incomplete) picture of catastrophic damages than the 95th.

4. ***Recommendations for the Interagency Working Group.*** Many of the problems with the SCC, as estimated here, cannot be addressed within the timeframe of this rulemaking; we therefore have a number of recommendations that we suggest EPA request from the Administration in the next Working Group revision, in addition to Recommendations 3 -9 above.

Recommendation #10:
Incorporate risk aversion into the next revision of the SCC. In doing so, risk aversion should be separated from the elasticity of marginal utility and inequality aversion. Currently, some methods assume all three concepts can be captured in the same

[18] NRDC made these suggestions in its comments on the proposed light duty vehicle standards, Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, 74 Fed. Reg. 49454 (September 28, 2009), but the Administration did not implement the first—offering no justification—and we would argue inadequately implemented the second.

parameter in the utility function, the "coefficient of relative risk aversion" in the Ramsey discounting approach (see Section II.b). Both empirically and theoretically, correlations between the three concepts are tenuous, particularly in the context of climate change, where losses occur over both space and time (Atkinson et al., 2009).[19] Sensitivity analyses over different available methods could be employed if appropriate.

<u>Discussion.</u> *It is widely recognized that risk aversion to catastrophic outcomes is a critical component to how people would value climate mitigation efforts. However, the Working Group chose not to incorporate risk aversion in its estimate of the SCC.*

<u>Recommendation #11:</u>
To better capture high and potentially catastrophic damages, adopt Weitzman's (2009)[20] suggestion of "extending the grid" in the Monte Carlo simulations (i.e. increase the number of, and value for, low probability catastrophic damages). A stylized example of what it means to "extend the grid" in a Monte Carlo simulation is provided in Section III.

<u>Recommendation #12:</u>
For catastrophic outcomes that affect the entire globe, such as a complete melting of the West Antarctic ice shelf or Greenland's glaciers, or collapse of the earth's ecosystem, use a damage value implied by Weitzman's (2009) analysis: the value of a statistical life (VSL) multiplied by the global population. (The VSL has been much maligned: contrary to how it sounds, it does not measure the value of an actual person. Rather, it estimates what individuals are willing to pay to reduce their risk of death).[21] Weitzman shows that, in the context of climate change, expected utility theory can imply an infinite value for the SCC. To resolve this, he suggests that losses be bound by a number that best approximates something like "the value of statistical civilization as we know it or maybe even the value of statistical life on Earth as we know it." Weitzman acknowledges that to some degree using the VSL is arbitrary, but argues it may be the best available choice. We note that this recommendation implies that losses would exceed world GDP, something IAMs often rule out (i.e. losses are (incorrectly) bounded by world GDP).

<u>Recommendation #13:</u>
Following the PAGE model, integrate a general "adaptation" function into all models that can vary by level, speed, and cost; inform lower bounds by a review of adaptation measures (or lack thereof) being taken for climate damages that have already begun. Default assumptions concerning the percentage of damages that can be eliminated by low-cost adaptation should include lower values than those in PAGE09

[19] Atkinson, G, Dietz, S, Helgeson, J, Hepburn, C, and Sælend, H (2009). Siblings, Not Triplets: Social Preferences for Risk, Inequality and Time in Discounting Climate Change. Economics: The Open-Access, Open-Assessment E-Journal, Vol. 3, paper no. 2009-26. http://www.economics-ejournal.org/economics/journalarticles/2009-26
[20] Weitzman, M (2009). On Modeling and Interpreting the Economics of Catastrophic Climate Change. Review of Economics and Statistics 9(1): 1-19.
[21] Literally, the VSL is based on an estimate of what individuals are willing to pay to reduce their risk of death by 1/100,000. The VSL represents the sum of 100,000 individuals' willingness to pay for this risk reduction.

(which themselves were substantially reduced from PAGE2002, the version used by the Working Group).[22] All three parameters (level, speed, and cost) should be randomized in the Monte Carlo simulations, to reflect how uncertain adaptation capacities will be. Given the possibility of adaptation with unintended consequences (what the IPCC refers to as "negative adaptation," for example, afforestation to prevent soil erosion increasing the amount of land vulnerable to forest fires), adaptation levels of zero or close to zero are possible and should be included.

Recommendation #14:

To the extent that different sectors of the economy are modeled in the IAMs, modify the "damage functions" to allow for cross-sectoral impacts. For example, there should be an interactive term between extreme weather events or epidemics, and the mass migration that could result from either.

Discussion. *In addition to risk aversion, the very high and catastrophic damages to which individuals are risk averse are not sufficiently integrated in the models. Multiple "fat-tail" distributions (see footnote 2) over different climate outcomes are not accounted for (only a fat tail for climate sensitivity is modeled). Also understating costs are model assumptions that adaptation will be low cost and available, which may not turn out to be the case. Finally, cross-sectoral (see footnote 1) damages are not modeled.*

Recommendation #15:

Equity weight within generations (just as the Working Group (implicitly) did between generations through discounting), using the different established methodologies available (i.e. do a sensitivity analysis using different methods). Given uncertainty over future generations' income levels and income distributions within any given time period, the Administration should present both equity-weighted and non-equity weighted SCC estimates. As with risk aversion, equity weighting that treats the elasticity of marginal utility, inequality aversion, and risk aversion (see Section II.b) as having the same value should be avoided, as both empirically and theoretically the correlation between the three concepts is tenuous (Atkinson et al., 2009[23]).

Recommendation #16:

Use one global value for the value of a statistical life (VSL), i.e., do not vary the value by income or the expected number of life years remaining (as is currently done in some models). Applying VSLs weighted differently by income levels, as is currently done in some models, is the reverse of equity weighting.

Discussion. *As noted in the introduction, the centuries-long impacts of greenhouse gases emitted today make the choice of the discount rate particularly contentious, because the farther into the future climate damages occur, the smaller the weight assigned to them as a result of discounting. Discounting at too great a rate could result in a heavy bias*

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[22] The PAGE model currently has this capacity, while most other models do not.

[23] Atkinson, G, Dietz, S, Helgeson, J, Hepburn, C, and Sælend, H (2009). Siblings, Not Triplets: Social Preferences for Risk, Inequality and Time in Discounting Climate Change. Economics: The Open-Access, Open-Assessment E-Journal, Vol. 3, paper no. 2009-26. http://www.economics-ejournal.org/economics/journalarticles/2009-26

toward favoring the current generation and ignoring catastrophic damage several generations hence. Greenhouse gas emissions also affect the entire earth's atmosphere regardless where they occur. A perverse consequence of this is that many of the world's poor, who neither emitted the gases nor benefited from the economic growth that ensued, will be disproportionately impacted. This makes decisions about "equity weighting" important and controversial.[24]

Equity weighting is not uncommon, and claims that it is too difficult to implement are not a sufficient excuse for failing to do so. Equity weights are used in the academic literature, as well as by the UK, Germany, and the European Union. The U.S. Census also provides a schedule for equity weights.

Recommendation #17:

Develop a multiplication factor(s) for non-use values, and apply them to appropriate use values included in the integrated assessment models. While a multiplication factor would be imprecise, it would arguably be less so than the assumed damage functions in the integrated assessment models, as there are a number of economic valuation studies on use- versus non-use resource amenity values, compared to none for damage functions. Imprecision would not be a legitimate reason against developing a multiplication factor, given the current state of (probably much greater) imprecision in the models' damage functions.

Discussion. *Research suggests that individual users of natural resources generally have a higher willingness to pay to preserve them than individuals who get only "existence value" (i.e. "non-users"). However, because there are so many more non-users than users, the sum of non-users' willingness to pay can be significantly larger than that of users (see, for example, Banshaf et al., 2006*[25]*). For example, damaged natural habitats such as coast lines or coral reefs will have a greater non-use than use value. This implies that non-use values are some multiple of use values.*

Recommendation #18:

Dedicate full-time Working Group staff to collecting, reviewing, and assimilating new climate science and economic modeling findings on an ongoing basis, so that revisions to the SCC can be accomplished more quickly. Literature should not be collected and reviewed just before an SCC revision has been initiated, as that will significantly delay how long it takes complete it.

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[24] Equity weighting refers to weighing damages to poor countries more heavily than those to wealthy countries in any given time period. This is distinct from changes in wealth over time. To the extent that developing countries become wealthier in the future from current high emission levels (e.g. China), the resulting growth in income over time is effectively accounted for by discounting. More precisely, the more a country's income is assumed to grow (which increases with assumed emission levels), the lower the present value of climate damages. In this sense, discounting "equity weighs" damages over time, even though it is not formally referred to as "equity weighting."

[25] Banshaf, HF, Burtraw, D, Evans, D, and Krupnick, A (2006). Valuation of Natural Resource Improvements in the Adirondacks. Land Economics 82(3): 445–464.

Recommendation #19:
Establish an EPA web page posting these new findings, and provide links to relevant research papers.

Discussion. With climate science evolving so rapidly, every revision of an SCC model is necessarily outdated by the time it is released, because the economic estimates of the damages included in the models significantly lag climate science by the time they are published. Thus it is important that the Working Group and EPA create structures to better process and convey the updated science and its implications for economic estimates of damages.

Recommendation #20:
Ensure that the Working Group's models, especially FUND, more accurately capture agricultural impacts; to the extent that this is not possible, CO2 fertilization benefits should be reduced to reflect what net impacts would be if it were possible to account for all effects.

Discussion. A very large benefit in the FUND model, increased agricultural productivity from CO2 plant fertilization, may be significantly overestimated. Recent research suggests fertilization benefits are lower than originally thought, and that many negative climate impacts on agriculture (e.g. extreme heat events, pests, and weeds) may overwhelm them, resulting in net agricultural losses.[26,27,28,29]

Recommendation #21:
Review current research on worse-case emissions growth scenarios and make sure the research is consistent with the scenarios used by the Working Group.

Discussion. Recent estimates of emissions in developing countries suggest that the upper ends of the 612 to 889 ppm of CO2 in the four business-as-usual scenarios used by the Working Group may longer be a worse-case estimate (Masur and Posner, 2010).[30,31]

[26] Lobell, D, Schlenker, W and Costa-Roberts, J (2011). Climate Trends and Global Crop Production Since 1980. Science 333 no.6042: 616-620.
[27] Fisher, A, Hanemann, M, Roberts, M, and Schlenker (forthcoming), W. The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather: Comment. American Economic Review, *forthcoming.*
[28] Roberts, M, and Schlenker, W (forthcoming). Is Agricultural Production Becoming More or Less Sensitive to Extreme Heat? Evidence from U.S. Corn and Soybean Yields. NBER Conference: The Design and Implementation of U.S. Climate Policy, *forthcoming*.
[29] Schlenker,W and Roberts, M (2009). Nonlinear Temperature Effects indicate Severe Damages to U.S. Crop Yields under Climate Change. Proceedings of the National Academy of Sciences, 106(37): 15594-15598.
[30] Masur, JS, and Posner, EA (2010). Climate regulation and the limits of cost-benefit analysis. John M. Olin Law & Economics Working Paper No. 525 and Public Law and Legal Theory Working Paper No. 315.
[31] A higher the CO2 concentration would result in a higher social cost of carbon if every additional ton of CO2 causes more damage than the previous, as concentration levels go up.

II. Background Material on Discounting and Equity Weighting

a) Ramsey discounting

The Ramsey discounting framework is based upon an equation derived from the economic theory of the consumer. It is the sum of the pure rate of time preference ( ) and the multiplication of two terms: the elasticity of marginal utility (η) and the GDP growth rate (g). Formally, the equation is: social discount rate = + ηg.

The parameter captures a tendency to prefer experiencing utility from consumption today rather than delaying it into the future, discussed further below under c).

The parameter represents the idea that as one's income increases, each additional dollar brings less utility. For a given individual, in the context of the social cost of carbon, damages would be weighed less the richer the person becomes over time, as each additional dollar's worth of damage brings less "dis" utility at higher income levels. In an intergenerational context like climate change, η also weights additional income (or losses in income) *between* individuals *across different generations*. In this sense, it serves as a sort of equity weight over time as the economy grows (or shrinks). (Unfortunately, to make matters confusing, this is not referred to as "equity weighting"; that term applies to weighting damages between *individuals in a given time period* based upon individuals' income levels—this does not involve discounting. A number of authors have used as equity weights the value of used for discounting). More precisely, a dollar's worth of damages to a poor person today is valued more highly than a dollar's worth of damage to a wealthier person in the future.

The growth term, g, correspondingly captures changes in income over time. If g is positive, the discount rate increases; if it is negative, it decreases. With income growing, an extra dollar of damages to a future person is weighted less than one to a current person, because that future person has more wealth (i.e., the additional dollar's worth of damage has a smaller "utility" loss). If income is *declining* over time, the weighting would be applied in reverse: a dollar's worth of damage to a future person would be valued *more highly* than a dollar's worth of damage to a current person. The sign of the growth rate is thus critical in how damages are weighted between generations. With climate change, this relationship takes on particular significance, because very high damages could result in a negative growth rate, and therefore a lower (or possibly negative) discount rate. If is set to zero, the discount rate would be unambiguously negative.[32]

[32] Note that this is distinct from an insurance framework, which would imply a negative *market* interest rate (expected returns from buying an insurance policy are negative (see point c) below). Here, damages are weighted based upon marginal utility and equity.

b) The triple role of

As discussed above, has been used to reflect an individual's marginal utility (i.e., weighting damages to oneself based upon one's income level), as well as an individual's "inequality aversion" (i.e., weighting damages across individuals according to income levels, both over time (discounting) and across space ("equity weighting")).

There is one more role that plays: the "coefficient of relative risk aversion." A complete discussion of this parameter is beyond the scope of this submission. We simply note here that, both theoretically and empirically, correlations between the three concepts are tenuous, particularly in the context of climate change, where losses occur over both space and time. The reader is referred to Atkinson et al. (2009) for a more complete discussion.

c) The "pure rate of time preference," , in the Ramsey equation, and in market interest rates

Both the Ramsey framework and discounting based upon descriptive market interest rates have a "pure rate of time preference," or impatience, component to them. In the Ramsey equation it is explicit, given by . In market interest rates it is implicit; it is part of the return lenders require based upon their preferences for consumption today over the future. Evidence suggests a central estimate for of approximately 1.5%;[33] some papers use values as high as 3% and 4%.

As discussed in Section I, we object to the use of market interest rates for discounting because they assign greater value to damages occurring closer in time than those farther out based solely upon when a person is born, assigning a preference for people born earlier over those born later. Many argue that only a value of zero makes sense for in the context of climate change, since many people will experience damages in the future that are not the same people benefitting from emitting CO2 today.[34] As OMB Circular A-4 notes, "Although most people demonstrate time preference in their own consumption behavior, it may not be appropriate for society to demonstrate a similar preference when deciding between the well-being of current and future generations. Future citizens who are affected by such choices cannot take part in making them, and today's society must act with some consideration of their interest." (OMB Circular A-4, p.35).

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[33] Her Majesty's Treasury (2003). The Green Book: Appraisal and Evaluation in Central Government, Treasury Guidance. Nordhaus (2011) uses 1.5% as a default value in a recent analysis. Nordhaus, W (2011). Esimates of the social cost of carbon: background and results from the RICE-2011 model. Cowles Foundation Discussion Paper No. 1826.

[34] The Stern Review used a rate of pure time preference of 0.1% per year, based on an arbitrary estimate of the annual probability that the human race will not survive (though it adopted the view that damages to future should not be discounted on the basis of the current generation preferring to consume now at the expense of future generations). Stern, N (2007). The Stern Review; The Economics of Climate Change. Cambridge, UK: Cambridge University Press, available online at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

d) Discounting framework versus an insurance framework

As discussed in Section I, we also object to using market interest rates as discount rates because this assumes that investors in a market for mitigation, were it possible for one to exist,[35] would require similar returns and risk levels as those observed in asset markets today. This assumption is wrong on several counts.

First, basing climate change discount rates upon observed markets cannot possibly be correct: the worst-case scenario when investing in regular asset markets is that an individual loses all of his or her life savings. This is hardly comparable to the kinds of catastrophic societal risks possible from climate change.

Second, theoretically, mitigation investments are more appropriately viewed as an insurance problem, not a profit-maximizing venture. Mitigation is a precautionary investment, and precautionary investments yield their highest returns in "bad" states of nature, not when asset markets are at their peak.

These two factors point to adding a *negative* risk premium to any descriptive discount rate, with a correspondingly a higher weighting of losses.[36] The negative "returns" individuals are willing to pay for in insurance markets, as evidenced by actuarial data, provide an example: purchasers pay to insure themselves against very bad outcomes that may never happen.

Unfortunately, the insurance analogy understates the case. With standard insurance policies:

a) Damages are often fully recoverable (i.e. not irreversible), examples being property damages resulting from fires or automobile accidents.[37]
b) The probabilities of bad outcomes generally are known. But they are not known in climate change, and people are more averse to investing in risky assets if the potential losses and the probability of those losses are uncertain (Gollier, 2009).[38] This is called "ambiguity aversion" in the literature. Gollier shows that under certain plausible conditions,[39] aversion to ambiguity will decrease the discount rate, and could do so quite substantially.
c) The probabilities of catastrophic outcomes in climate change are *higher* than those observed in insurance markets.

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[35] A "mitigation investment" would be any action whose purpose is to reduce climate change impacts by reducing greenhouse gas emissions. A market for such investments could not exist, however, because mitigation is a public good: any individual's investment, by itself, would not impact climate change, so there would be no incentive to make such investments. In addition, any benefits resulting from an individual's investment benefit everyone, regardless of whether they contribute to the investment or not, creating a "free-rider" problem and underinvestment. As a public good, mitigation must be invested in collectively at a large scale.
[36] Cochran, JH (2001). Asset Pricing. Princeton: Princeton University Press.
[37] Minus any deductibles.
[38] Gollier, C (2009). Portfolio choices and asset prices: The comparative statics of ambiguity aversion. Toulouse School of Economics (LERNA and IDEI) working paper.
[39] These conditions are: 1) as income rises, a person is more willing to increase investments in assets that are risky, whose risk level and size of potential loss is known; and 2) as income rises, a person is more willing to invest in assets with uncertain losses and uncertain probabilities of such losses.

Because the negative discount rates implied by an insurance approach do not lead to sensible policy conclusions in cost-benefit analysis (see Section I.2), we recommend as a middle ground a discount rate of .7%, the average return on 6 month U.S. Treasury Notes. We consider this a better measure of the risk-free rate of return than the yield on long-term U.S. Treasury Bonds (which carry inflation risk), the rate chosen by the Working Group.

A second option for a descriptive discount rate, but one which we consider less desirable than the risk-free rate of return, would be to use regular returns in markets adjusted for uncertainty in future interest rates, using declining rates over time, as prescribed by Weitzman (2001),[40] Newell-Pizer (2003), and the UK government. The UK government bases its schedule[41] upon the work of Weitzman (1998, 2001), Gollier (2002),[42] and a specially commissioned report by OXERA.[43] The UK schedule provides declining discount rates with and without a "pure rate of time preference"; only the latter schedule (see discussion above on the rate of time preference) should be considered.[44]

e) Adjusting the discount rate for negative externalities

Another reason market interest rates are not appropriate for discounting is that they do not take into account many things that decrease real output, such as depreciation of natural capital (e.g., loss of natural habitats to development) and pollution externalities (e.g., non-CO2 pollutants from burning fossil fuels.[45] We can get a sense of size of this distortion by looking at efforts made to adjust GDP estimates that take such factors into account. Estimates vary widely, depending upon the year(s) examined and different methodologies, but all find adjusted growth to be lower than unadjusted.

A collection of estimates presented in Goodstein (2004), based upon studies and data from various authors, show a range of adjusted annual per capita growth .2 to 3.1 percentage points lower than annual per capita GDP growth, for various time periods.[46] One study relied upon data

[40] Weitzman, M (2001). Gamma Discounting. American Economic Review, American Economic Association, vol. 91(1): 260-271.

[41] Lowe, J (2008). Intergenerational wealth transfers and social discounting: supplementary green book guidance. UK Treasury. http://www.hm-treasury.gov.uk/d/4(5).pdf

[42] Gollier, C (2002). Time horizon and the discount rate. IDEI, University of Toulouse, mimeo. Gollier, C (2002). The Economics of Risk and Time. Cambridge, MA: MIT Press. Gollier, A (2002). Discounting an uncertain future. Journal of Public Economics (85): 149-166. Gollier, C (2002). Time Horizon and the Discount Rate. Journal of Economic Theory 107(2): 463-473.

[43] OXERA report for ODPM (2002), A social time preference rate for use in long-term discounting, a report for ODPM, DfT and Defra.

[44] The schedule is as follows:

	0-30 years	31-75 years	76-125 years	126-200 years	201-300 years	301+ years
UK Treasury Discount Rate Schedule	3.00%	2.57%	2.14%	1.71%	1.29%	.86%

Note: The *Stern Review* used a discount rate of 1.4%.

[45] GDP also excludes things that increase welfare, such as any household labor that is not bought and sold in the market. On net, however, it excludes significantly more "bad" things than "good" things.

[46] Goodstein (2004). Economics and the Environment, 3rd edition. Wiley: Hoboken, NJ.

from Nordhaus and Tobin (1972),[47] another from Zolatas (1981),[48]and a third from Daly and Cobb (1989).[49] The Nordhaus and Tobin estimates had a .7 percentage point difference in annual per capita growth between 1929 and 1965, and a 1.8 percentage point difference between 1947 and 1965. Zolatas' differences were 1.8 (1947-1965), 1.6 (1950-1965), and 1.5 percent (1965-1977). Daly and Cobb estimated .2 (1950-1960), .6 (1960-1970), 3 (1970-1980) and 3.1 (1980-1986). In another source, Stewart (1974), using the data from Nordhaus and Tobin, estimated differences in GDP *levels* (as opposed to growth rates) of 1 and .9 percentage points lower for two specific years, 1929 and 1965.[50] A more recent estimate over the full time period of 1950 to 2006 estimated an annual per capita adjusted growth rate 2.5 percentage points below GDP.[51] Some of the studies from Goodstein were peer-reviewed. Stewart's was also peer reviewed. The Redefining Progress report, Zolatas, and Daly and Cobb likely were not.

[47] Nordhaus, W, and Tobin, J (1972). Is growth obsolete? In Economic Research: Retrospect and Prospect Vol 5: Economic Growth, National Bureau of Economic Research.
[48] Zolatas, X. (1981). Economic Growth and Declining Social Welfare. New York: New York University Press.
[49] Daly, H and Cobb, J (1989). For the Common Good. Boston: Beacon Press.
[50] Stewart, K (1974). National income accounting and the concept of economic welfare: the concepts of GNP and NEW. Federal Reserve Bank of St. Louis.
[51] Talberth, J, Cobb, C, and Slattery, N (2007). The Genuine Progress Indicator 2006: a Tool for Sustainable Development. Redefining Progress. Oakland: CA.

III. "Extending the Grid" in the Monte Carlo Simulations

In order to improve representation of catastrophic risk in the integrated assessment models, Weitzman (2009)[52] urges a more aggressive implementation of the Monte Carlo simulations. He suggests oversampling low probability/high damage outcomes, and expanding the "grid size" to extend farther out into the fat tail (i.e. allow for higher damages than currently modeled).

Weitzman proposes a sophisticated statistical methodology to do this, the details of which are beyond the scope of this submission. However, we can provide an oversimplified stylized example of the effect of the methodology. Suppose possible damages are $10, $15, $20, $50, and $100, and their estimated probabilities 50%, 25%, 15%, 8% and 2%, respectively. To over sample in the Monte Carlo analysis, you might specify that 60% of the draws come from the $20-$100 range, and the other 40% from the $10-$15 range. This would over sample the right end of the distribution (and under sample the left), because the sum of the probabilities of $20, $50, and $100 is only 25%.

After one of the ranges is selected using the 40%/60% sampling rule, you might then weigh the probabilities within the selected tranche relative to one another. In this example, if the "coin is tossed" and the computer is assigned to choose $10 or $15 (which would happen in approximately 40% of the runs), the computer would be two times more likely to pick $10 than $15, since its original probability (50%) is twice that of $15 (25%). To "expand the grid size," you might add a damage value higher than $100, and accordingly reassign probabilities on that end of the tail. For example, you might assign $100 a probability of 1.5%, and add a .5% chance of $200.

Experimentation within the literature suggests that the effect of expanding the grid size is likely to be dramatic, regardless of which of the three main models are used (DICE, FUND, and PAGE). Dasgupta (2007) notes that if Nordhaus's DICE model is run using a more catastrophic worse-case scenario, the SCC increases by $68/tCO2.[53] Ceronsky, Anthoff, Hepburn, and Tol (2005) use FUND to recalculate the SCC adding the potential for three types of non-linear catastrophic climate responses: thermohaline collapse,[54] methane gas hydrate dissociation,[55] and high climate sensitivity.[56] The estimated SCCs increased from $16/tCO2 to $910/tCO2 (2008$).[57] Finally, Ackerman, Stanton, Hope and Alberth (2009) demonstrate using the PAGE

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[52] Weitzman, M (2009). On modeling and interpreting the economics of catastrophic climate change. Review of Economics and Statistics 91:1-19.

[53] Dasgupta, P (2007). Commentary: The Stern Review's economics of climate change. National Institute Economic Review 199(4). Converted from $t/CO2 (dollar denomination not given).

[54] Thermohaline refers to the ocean's circulation pattern that moves warm water towards colder regions in the ocean. Among other things, its collapse could return Europe to ice age conditions.

[55] This term refers to the melting of the West Antarctic permafrost causing large quantities of methane to be released, a greenhouse gas that is 23 times more powerful than CO2. As a separate matter, the Arctic also contains more carbon dioxide than the entire atmosphere holds today.

[56] The temperature increase predicted from a doubling of CO2 levels above preindustrial levels.

[57] Ceronsky, M., D. Anthoff, C. Hepburn and R.S.J. Tol. (2005) Checking the Price Tag on Catastrophe: The Social Cost of Carbon under Non-linear Climate Response. *Research unit Sustainability and Global Change, Working*

model that projected global GDP damages increase in 2100 from 2.2% under traditional "best guess" assumptions,[58] to 16.8%, looking at the 95th percentile and using more pessimistic assumptions (no adaptation, higher expected temperature increases, increased damages, and increased risk of catastrophe) than the model's default scenarios. For the U.S., GDP losses in 2100 increased from .4% to 4.3%.[59]

Paper FNU-87, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg. http://www.fnu.zmaw.de/fileadmin/fnu-files/publication/working-papers/catastrophewp.pdf

[58] Interestingly, this is the number that Stern would have arrived at had he ended his model in 2100. His damage estimates of 5-20% of global GDP were driven in large part by many of the worst damages happening after 2100, which were then "amortized" over the full time horizon of the model.

[59]Ackerman, F, Stanton, E, Hope, C and Alberth, F (2009). Did the Stern Review underestimate US and global climate damages? Energy Policy 37: 2717–2721.