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The Role of Integrated Assessment Models in Climate Policy: A User's Guide and Assessment

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***The Role of Integrated Assessment Models in Climate Policy:
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Abstract

This paper considers the role of integrated assessment models (IAMs) in the construction of climate policy. We focus on questions involving the role of IAMs in estimating the social cost of carbon (SCC), how best to handle the considerable scientific uncertainty underlying the IAMs from the perspective of estimating the SCC, and whether an IAM-based SCC should be abandoned and replaced by expert judgment or another substitute. The perspective we adopt in tackling these questions is rooted in the specific needs of the existing U.S. institutions responsible for making and implementing climate policy, specifically regulatory agencies within the Executive Branch and Congress should it choose to take up climate legislation.

Our discussion has three premises. First, policy makers need a numerical value and an uncertainty range for the SCC for policy evaluation and implementation. Second, whatever the true value of the SCC is, it is not zero. Third, considerable uncertainty surrounds the current state of scientific knowledge about the current and future costs of climate change. The evolving nature of the science and the ultimate goal of informing first-best policy suggests to us that the official SCC – the SCC used for regulatory analysis by the U.S. Government – should not be thought of as a single number or even a range of numbers, but more broadly as a process that yields updated estimates of those numbers and ranges. Viewed in this way, the ultimate goal of the process is scientific credibility, public acceptance, and political and legal viability.

Keywords: Climate Change, Social Cost of Carbon, Integrated Assessment Models, Climate Policy

JEL Codes: Q54, Q58

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***The Role of Integrated Assessment Models in Climate Policy:
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I. Introduction

Greenhouse gas emissions are a textbook case of a global externality. The starting point for any policy to address this market failure is an assessment of the monetized social marginal damages from emissions – the net damages arising from one additional ton of emissions in any given year. The classic prescription for an externality of this type is to set a price on emissions equal to the social marginal damages. This can be done in the form of a Pigouvian tax (Pigou, 1932) or by establishing property rights to pollution through cap and trade systems (see the seminal treatment by Dales, 1968) where the equilibrium trading price of emissions is set by the intersection of demand for emissions and the fixed supply of emission allowances set by policy. Whether a price on emissions is set by a tax or through a cap and trade system, optimal policy design requires knowledge of the social marginal monetized damages from greenhouse gas emissions. In the case of CO₂ emissions, this marginal monetized externality value is known as the Social Cost of Carbon (SCC).¹

While theoretically straightforward, estimating the value of the SCC is highly challenging on a number of dimensions. To date, academic researchers have relied heavily on integrated assessment models (IAMs) both to explore the pathways through which greenhouse gas emissions accumulate in the atmosphere and oceans and to assess natural and economic impacts. The current U.S. Government estimate of the SCC, or more precisely its central SCC value and three alternative estimates, were computed by the Interagency Working Group using three well known IAMs, initially in 2010 and using updated versions of those IAMs in 2013.²

The three papers in this symposium consider the challenge of estimating the SCC using IAMs, given the very large amount of uncertainty underlying many aspects of the IAM-based calculations.

¹ There is a vast literature on the pros and cons of using taxes as opposed to cap and trade systems to reduce greenhouse gas emissions going back to Weitzman (1974). Weitzman's analysis focuses on efficiency given the policy maker's ex ante uncertainty over marginal abatement costs. More recent analyses have focused more on the political benefits and costs of different policy approaches. See, for example, Metcalf (2007) and Stavins (2007) for one contrasting set of views. Another strand of the literature focuses on the Pigouvian prescription to set a price on emissions equal to the social cost of carbon. Bovenberg and de Mooij (1994) along with Parry (1995) noted that in the presence of pre-existing distortions the optimal price on emissions would likely fall short of the social marginal damages from emissions and sparked a large literature on the so-called "Double Dividend Hypothesis"; for recent contributions and references see Goulder (2013) and Jorgenson et al. (2013). These papers and nearly all subsequent theoretical work on policy design whether in a first or second best world assume that the monetized externality of a ton of carbon emissions (the social cost of carbon) is known.

² Greenstone, Kopits, and Woolverton (2013) provide an overview and discussion of the interagency process used to develop the SCC in 2010.

Weyant's paper reviews IAMs and argues that much of the uncertainty in the use of IAMs represents less the flaws of the models and more the fundamental uncertainty in scientific and economic knowledge of key model features and inputs. Weyant also stresses the importance of the research community improving how it reports and handles the wide range of uncertainty from IAM-based calculations. Pindyck's paper also focuses on the uncertainty in the IAMs but reaches a quite different conclusion, echoing the earlier criticism in Pindyck (2013) that the models are "of little or no value for evaluating alternative climate change policies and estimating the SCC" (p. 870) and that the models suggest "a level of knowledge and precision that is nonexistent, and allows the modeler to obtain almost any desired result because key inputs can be chosen arbitrarily" (ibid). Pindyck proposes that an IAM-based SCC be replaced with an SCC that reflects the combined opinion of a panel of experts.

This paper considers the role of the SCC in climate policy, the role of IAMs in estimating the SCC, how best to handle the considerable scientific uncertainty underlying the IAMs from the perspective of estimating the SCC, and whether an IAM-based SCC should be abandoned and replaced by expert judgment or another substitute. The perspective we adopt in tackling these questions is rooted in the specific needs of the existing U.S. institutions responsible for making climate policy, specifically regulatory agencies within the Executive Branch and Congress should it choose to take up climate legislation. Our discussion has three premises.

First, policy makers need a numerical value and an uncertainty range for the SCC for policy evaluation and implementation. In a regulatory context, the Office of Management and Budget (OMB) requires agencies to conduct cost-benefit analysis of major newly proposed regulations. These and other climate policies implemented by regulation under existing law are second best; first-best policies would require Congressional action. But setting the appropriate stringency of both first- and second-best policies depends on the monetized externality value of carbon emissions, that is, on the SCC.

Second, whatever the true value of the SCC is, it is not zero. In 2008, the U.S. Court of Appeals for the Ninth Circuit struck down the 2007 changes to the CAFE standards in part because it found that the National Highway and Transportation Authority had been arbitrary and capricious when it argued that the monetary benefits of greenhouse gas reductions were too uncertain to permit their use in regulatory analysis.³ Thus a specific, nonzero, value is needed; moreover, so that this value is neither arbitrary nor capricious, it should be based on the best available science.

³ Ninth Circuit Court of Appeals, *Ctr. for Biological Diversity*, 508 F.3d (9th Cir. 2007) as replaced by 538 F.3d 1200 (9th Cir. 2008); also see the discussion in NHTSA's revised proposed CAFE rule, 73 *Federal Register* 24361-2.

Third, considerable uncertainty surrounds the current state of scientific knowledge about the current and future costs of climate change. Although research is progressing rapidly on some fronts, we argue below that some important aspects of the uncertainty, such as the appropriate discount factor to use or the damages induced by extreme events far outside the range of historical human experience (such as melting of ice sheets), are unlikely to be resolved within the time frame necessary for making important and costly decisions on climate policy.

As we argue below, the evolving nature of the science and the ultimate goal of informing first-best policy leads us to conclude that the official SCC – the SCC used for regulatory analysis by the U.S. Government – should not be thought of as a single number or range of numbers, but more broadly as a process that yields updated estimates of those numbers and ranges. Viewed in this way, the ultimate goal of the process is scientific credibility, public acceptance, and political and legal viability.

Accordingly, we suggest that the process that results in an official SCC should satisfy five criteria⁴:

- 1) The estimate of the SCC should use the best available science and should be accompanied by quantified measures reflecting the uncertainty in the existing science, for example by providing a range in addition to a central focal estimate;
- 2) The method by which the SCC is computed should be transparent, replicable, and broadly explainable and understandable to non-experts;
- 3) The methodology should be subject to expert review and should incorporate regular updating;
- 4) The process should provide guidance to researchers to identify key sensitivities and areas where future research would be most productive for improving estimates of the SCC;
- 5) The process should not risk being viewed by the courts as arbitrary and capricious and it should be as isolated as possible from political influences.

While enhancing precision in the estimate of the SCC is desirable, improving precision is a process and we should expect that uncertainty about the SCC will persist for an extended period of time. Policy-making under uncertainty is the norm, and in this sense climate policy and the SCC is no different. Given the long time horizon for climate policy, however, both the policies and the analytical basis for those policies need to be able to incorporate and to adjust to newly available information.⁵

⁴ Our criteria are consistent with but not directly tied to the principles for regulatory design and review laid out in guidance such as Executive Order 12866 which sets out objectives and criteria for regulatory planning and review.

⁵ Interestingly, most models of optimal climate policy do not incorporate the stochastic nature of knowledge acquisition or climate outcomes, an understandable simplification given the computational challenges posed by optimal updating. A recent example of a study in which the carbon price changes as information is acquired (in this case, information about large-scale abrupt changes) is Cai, Judd, and Lontzek (2013).

These observations lead us to three conclusions. First, as we discuss in more detail below, in our view the process followed by the Interagency Working Group to estimate the SCC in 2010 and 2013, including its use of IAMs, fares well on many of these criteria. While it is certainly possible to imagine alternatives to the IAM-based process run by the U.S. government, the Interagency Working Group Process is more consistent with these criteria than alternatives such as different agencies using different values (as was done before the centralized efforts of OMB and the Interagency Working Group), failure to adopt any value (thereby implicitly adopting the clearly incorrect value of zero), or an expert panel charged with reaching a numerical judgment without reference to numerical models. This said, room remains for improving the current process. One such improvement is incorporating into the SCC process formal external expert review, and another is providing a schedule for regular updating, both suggestions recently made by Pizer et al. (2014).

Second, an ongoing challenge of the SCC process is how best to communicate the uncertainty surrounding estimates of the SCC while still providing a numerical value and range that can be used in the policy process. As Weitzman (2015) puts it, climate change is an application to which IAMs are likely to give "fuzzier" answers than usual cost-benefit analysis. In our view, a key challenge for the SCC process is balancing the tension that the SCC is subject to considerable uncertainty on the one hand, but on the other that the range of uncertainty does not plausibly include zero and that the policy process needs a SCC value and range that can be useful and actionable. We do not propose a single novel communications method for solving this problem, but do think that a process that meets the five criteria above has the best chance of tackling this communications problem in an ongoing way.

Third, the value of the SCC – whether computed using IAMs or in some other fashion that incorporates the best available science – will for the foreseeable future be provisional and subject to change. For example, the attention received by the official SCC has shown a spotlight on aspects of IAMs with considerable scientific uncertainty, such as the damage functions and the largely-unmodeled consequences of large-scale abrupt changes, and we point to vibrant new strands of research that could help to improve the IAMs and thus inform future revisions to the SCC. This combination of ongoing uncertainty and evolving estimates of the SCC requires a degree of sophistication in the public debate and in climate policies not normally required in other policy arenas.

Before developing these arguments, we first provide a brief history of the use of IAMs in U.S. climate policy, then examine the current official SCC and its uses. We then turn to the question of alternative processes for developing the SCC. We conclude that while the Interagency Working Group

process so far (including its use of IAMs) is sound and better than the alternatives, it is important to institutionalize a process for the ongoing improvement of the SCC consistent with the five criteria above.

II. IAMS and the Use of the SCC in Climate Policy

Nordhaus (2013b) defines integrated assessment models as "approaches that integrate knowledge from two or more domains into a single framework" (p. 1070). Nordhaus's definition is broad and includes a variety of models that, by themselves, do not generate estimates of the SCC.⁶ Models that can be used to estimate the SCC combine a model of the economy with a model of the atmosphere and ocean (and possibly land) that allows the researcher to track geophysical and economic variables of interest. An IAM constructed to address climate change must be able to track emissions, the concentration of greenhouse gases in the atmosphere as well as other carbon sinks, temperature and other climate impacts arising from increased concentrations of greenhouse gases in the atmosphere, and damages resulting from those climate impacts. Emissions follows from economic behavior, and policies scenarios can be posited to affect emissions along a number of dimensions. Figure 1 (adapted from Nordhaus, 2013b) illustrates the modules (rectangles) and model inputs/outputs (parallelogram) of a generic IAM. Not all IAM's contain all of the elements in Figure 1. For example, we are not aware of any IAM that contains an explicit political response module that models how policy makers react to climate change damages through policy actions that lead to emission reductions.⁷

Early Regulatory Applications of the SCC. Prior to the Interagency Working Group's effort, estimates of damages from greenhouse gas emissions were incorporated into regulatory analyses in an ad hoc way that varied across agencies and rules. Some examples illustrate the evolution of thinking as well as differing agency views on SCC estimates.

The March 2006 National Highway Transportation Safety Administration (NHTSA) Final Regulatory Impact Analysis setting forth fuel economy standards for Model Year 2008-2011 light trucks states that

⁶ The U.S. National Energy Modeling System (NEMS) is a good example of this latter type of model. NEMS is comprised of a number of modules representing energy supply (e.g. oil and gas, coal, renewable fuels), energy demand (residential, commercial, industrial, and transportation) and conversion modules (e.g. electricity, petroleum markets, international energy) and can produce detailed scenarios of future energy pathways. While it can be used to generate future emission scenarios under different policy assumptions, it lacks the climate, ecosystem, and damage modules that would be necessary to develop estimates of the SCC.

⁷ IAM modeling exercises typically model political response as part of a given scenario. Reference case scenarios in which no action is taken to address climate change assumes one implicit political response while optimal policy scenarios posit a different political response that sets an implicit or explicit price on greenhouse gas emissions at the optimal rate.

"[t]he agency continues to view the value of reducing emissions of carbon dioxide and other greenhouse gases as too uncertain to support their explicit valuation and inclusion among the savings in environmental externalities from reducing gasoline production and use. There is extremely wide variation in published estimates of damage costs from greenhouse gas emissions, costs for controlling or avoiding their emissions, and costs of sequestering emissions that do occur, the three major sources for developing estimates of economic benefits from reducing emissions of greenhouse gases. ... As a consequence, the agency has elected to include no economic value for reducing greenhouse gas emissions ... among the benefits of reducing gasoline use via more stringent fuel economy regulation." U.S. Department of Transportation (2006), pp VIII-64 – 65.

In 2008, the U.S. Ninth Circuit Court of Appeals held that, by failing to monetize the benefits of GHG emissions reductions, NHTSA had acted arbitrarily and capriciously, and for this and other reasons remanded the rule to NHTSA to set new standards. The court stated that, "[w]hile the record shows that there is a range of values, the value of carbon emissions reduction is certainly not zero."⁸

Accordingly, in May 2008 NHTSA issued a proposed rule for MY 2011-15 passenger cars and light trucks that incorporated a SCC value of \$7 per ton CO₂e (2006 dollars). NHTSA arrived at this result by averaging a high value of \$14 per ton (based on estimates from the IPCC's Fourth Assessment Report and adjusted forward to 2011) with a low value of zero. This latter estimate is based on measuring damages to the U.S. economy only: "Although this finding suggests that the *global* value of economic benefits from reducing carbon dioxide emissions is unlikely to be zero, it does not necessarily rule out low or zero values for the benefit to the U.S. itself from reducing emissions" (U.S. Department of Transportation, 2008a, p. 24414, emphasis in original).

In the Agency's final environmental impact statement for the MY 2011-2015 fuel economy standards released five months later, SCC estimates of \$2 per ton CO₂e (based on domestic benefits only) and \$33 per ton (based on global benefits) were used U.S. Department of Transportation (2008b). The Agency based its increase in global benefits from \$14 to 33 per ton on new and updated estimates of the SCC contained in Tol (2008). It also used a positive value for U.S.-only benefits based on an assessment of the ratio of U.S. to global benefits of emission reductions.

In its proposed rule for regulating greenhouse gas emissions under the Clean Air Act, the U.S. Environmental Protection Agency (2008) used four values of the SCC in a side analysis to estimate benefits of reducing emissions. EPA used global benefit estimates of \$40 and \$68 per ton CO₂e based on discount rates of 3 and 2 percent, respectively and domestic benefit estimates of \$1 and \$4 (again for

⁸ *Center For Biological Diversity v. Nat'l Highway Traffic Safety Admin.*, 538 F.3d 1200 (9th Cir. 2008). This opinion replaced an earlier 2007 opinion (508 F.3d).

discount rates of 3 and 2 percent) based on a meta-analysis building on Tol (2008).⁹ In all cases these estimates are for emission reductions in 2007 and are measured in year 2006 dollars. Despite reporting benefit estimates that include a SCC estimate, the EPA made clear that the agency was not endorsing a particular SCC value.¹⁰

In an effort to better understand the externalities associated with energy production and consumption, Congress directed the Department of Treasury in 2005 to commission a study by the National Academy of Sciences to investigate this issue. A committee was formed to undertake this task and included in its statement of task the following activity: "[d]evelop an approach for estimating externalities related to greenhouse gas emissions and climate change. Estimate externalities related to those changes" (National Research Council, 2009, p. 18). The committee concluded after an extensive survey of the literature that the SCC could range by two orders of magnitude – from \$1 to \$100 per ton CO₂-equivalent – depending on the choice of discount rate for discounting future damages from climate change and the degree of damages from climate change (see Table 1). The report states that "at this point only order-of-magnitude estimates appear warranted" (p. 218).

While unsatisfying from the perspective of not providing a SCC number for use in regulatory impact analysis, the NRC study highlighted two of the key modeling choices (discount rate and damage function) that drive estimates of the SCC, issues we return to below.

The Interagency Working Group and the Current SCC. The Interagency Working Group used three widely known and respected IAMs to develop an official SCC.¹¹ The Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) model has been used extensively by the IPCC; its developer, Richard Tol, as noted above, has carried out several meta-analyses on the social cost of carbon relying on his and other modelers' work. The Policy Analysis of the Greenhouse Effect (PAGE) model, developed by Chris Hope was most prominently used in the analysis of the *Stern Review* (2007) . The Dynamic Integrated Climate and Economy (DICE) model, developed by William Nordhaus, is especially

⁹ EPA's global SCC of \$40 and \$68 (depending on the discount rate) differ from NHTSA's estimate of \$33 despite the underlying data in both cases coming from Tol (2008). NHTSA averaged the 125 estimates in the Tol meta-analysis while EPA focused on studies concluded since 1995 and separated out estimates of the SCC according to the underlying discount rate. Without criticizing the work either of NHTSA or EPA, the divergent SCC estimates speak to the value of an official SCC number (or set of numbers).

¹⁰ "Presentation of these values does not represent, and should not be interpreted to represent, any determination by EPA as to what the social cost of carbon should be for purposes of calculating benefits pursuant to the Clean Air Act." U.S. EPA (2008), p. 44446.

¹¹ This section draws heavily on Interagency Working Group on Social Cost of Carbon (2010) and Greenstone, Kopits, and Woolverton (2013).

transparent given Nordhaus's posting of the model on his website along with the various books he has written documenting and using the model (Nordhaus and Boyer, 2000; Nordhaus, 2008; Nordhaus, 2013a).

After reviewing the literature, the Interagency Working Group ran the three models using five scenarios (sets of assumptions about emissions, economic growth, population growth and other socioeconomic assumptions) with 10,000 draws each from a Roe-Baker distribution of equilibrium climate sensitivity (ECS) calibrated to assumptions taken from the IPCC's Fourth Assessment Report. The ECS measures the long-term equilibrium increase in global average surface temperature due to a doubling of greenhouse gas concentrations in the atmosphere from pre-industrial era levels and is a critical parameter in climate models. For each of three assumed discount rates (2.5, 3 and 5 percent), the 150,000 model runs were generated (3 models x 5 economic scenarios x 10,000 runs) and the results were pooled with equal weight given to each model and scenario. For each run, marginal damages were constructed as the present discounted value of the change in per capita consumption from the reference case arising from a shock to emissions in a given year.¹² The Interagency Working Group reported mean values of marginal damages for each year for the 150,000 runs associated for each discount rate. In addition it reported the 95th percentile value from the 3 percent discount rate runs as one way to take into account potentially large tail impacts of climate change.

The 2013 SCC update replicated the methodology of the 2010 report but used updated versions of the FUND, PAGE, and DICE models. Table 2 shows estimates of the SCC for 2020 and 2050 from the two reports. Focusing on the 2020 estimates from the 2013 technical update, moving from a discount rate of 5 percent to 3 percent nearly quadruples the SCC and more than quintuples it when going to a 2.5 percent rate. The SCC at the 95th percentile of the distribution with a discount rate of 3 percent is triple the mean value. Similar patterns hold for the other years. The central estimate of the SCC in 2020 increases by 65 percent between the 2010 report and the 2013 technical update, reflecting among other things updating to the damage functions and explicit representation of sea level rise in two of the models.

¹² This approach could be extended to estimate the social cost of other greenhouse gases (e.g. methane). Directly measuring the social cost through modeling would be preferable to a social cost computed as the social cost of carbon times the global warming potential for other greenhouse gases. Global warming potential (GWP) measures the radiative forcing of a greenhouse gas over a specified time period (usually 100 years) that is equivalent to a given amount of carbon dioxide. Schmalensee (1993) and Reilly et al. (1999), among others, highlight the problems with using a GWP measure in lieu of an explicit analysis of marginal impacts of emissions of various greenhouse gases.

All three models used in the 2013 Interagency Working Group's calculations exhibit mean SCC estimates greater than the median for all the scenarios and discount rates, a consequence of a long right tail of the distribution of the SCC across simulations (see Tables A2-A4 in the 2013 report). While there is variation in the estimates based on the scenario under consideration, the greater variation occurs across equilibrium climate sensitivity (as evidenced by the range of estimates for any particular model, discount rate, and scenario), discount rates, and model.

The variation across models is particularly striking. The estimates from the FUND model are considerably lower on average reflecting lower damages at all temperature levels (at least in the 2010 analysis; see figures 1A and 1B). While the 2013 update does not provide information about damages as a function of temperature change, the FUND model consistently provides lower estimates of damages at any percentile for each scenario-discount rate combination. By taking simple averages across models and economic scenarios, the Interagency Working Group took no position on the relative merits of competing models or the likelihood of differing economic scenarios, an issue to which we return below.

Current Uses of the SCC. Currently the SCC is used as an input into official cost-benefit analyses of proposed regulations, as part of legal challenges to government actions, and as a measure of the costs of climate change in the public discussion about climate policy. We turn to examples of each of these three uses.

In June 2014, the U.S. Environmental Protection Agency (2014) released its regulatory impact analysis for proposed guidelines on carbon emissions from existing power plants (EPA's Clean Power Plan). EPA's summary of the estimated monetized benefits of the proposed rule includes four estimates of the benefits of reduced carbon dioxide emissions using the four estimates from the Interagency Working Group's 2013 technical update: mean averages at 2.5, 3.0, and 5.0 percent discount rates and the 95th percentile value from the distribution of estimated SCC's from the 3 percent discount rate run. Unlike previous NHTSA or EPA analyses, but consistent with the multiple prior uses of the Interagency Working Group's estimates,¹³ there is no attempt to disentangle global from U.S. benefits noting the distinctive nature of the climate change problem. Emissions of greenhouse gases contribute to damages around the world, even when they are released in the United States, and the world's economies are now highly interconnected. Therefore, the SCC estimates incorporate the worldwide damages caused by carbon dioxide emissions in order to reflect the global nature of the problem, and we expect other governments to

¹³ For example, prior regulatory uses of the SCC for cost-benefit analysis include multiple energy efficiency rules under the Energy Independence and Security Act, Sewage Sludge Incineration Emission Standards (75 *Federal Register* 63260), and Fuel Efficiency Standards for Medium- and Heavy-Duty Vehicles (75 *Federal Register* 74152).

consider the global consequences of their greenhouse gas emissions when setting their own domestic policies. (EPA, 2014, p. ES-14)

In keeping with numerous other cost-benefit analyses of energy/environmental regulations since OMB's adoption of the 2010 Interagency Working Group report, the 2014 Regulatory Impact Assessment (RIA) explicitly defers to the Interagency Working Group's estimate of the SCC. The RIA uses the Working Group's central value, the mean of the distribution of SCC estimates from runs where a 3 percent discount rate is assumed (Tables ES-8, 9, and 10 of the RIA).

The SCC appears in legal decisions as well. For example, the SCC played a central role in a June 2014 U.S. District Court judge's decision to rescind the U.S. Bureau of Land Management's (BLM) granting of a lease to Arch Coal to expand coal mining in an area of the Gunnison National Forest in Colorado (Jackson, 2014). In its quantification of the benefits and costs of the lease expansion, BLM had excluded any costs associated with the release of methane and other greenhouse gases arguing that "[s]tandardized protocols designed to measure factors that may contribute to climate change, and to quantify climatic impacts, are presently unavailable" (p. 17 of decision). The judge in the case explicitly rejected that claim finding that "... a tool is and was available: the social cost of carbon protocol," (p. 17) going on to describe the Interagency Working Group Technical Support Document. The decision notes that while the preliminary environmental impact statement had contained estimates of the climate impacts using the Interagency Working Group's SCC estimates, monetized climate impacts were excluded from the final environmental impact statement apparently in response to an email from a BLM economist who argued that the use of SCC was "controversial" citing the wide range of estimates both in the Interagency Technical Support Document as well as other sources. In effect, the existence of uncertainty over the SCC led BLM to replace a positive value for the SCC in the quantitative analysis it undertook with a value of zero. The judge deemed that decision "arbitrary and capricious" (p. 19 of decision). This decision marks a significant milestone in legitimizing the Interagency SCC by overturning a federal agency decision on the grounds that the working group's SCC estimates were not employed in the benefit cost analysis.¹⁴

The SCC also plays an important role in the public discussion of the costs of climate change and the monetized benefits of emissions reductions. A leading example concerns public discussions about what the appropriate value of a carbon tax might be. The American Opportunity Carbon Fee Act, a bill introduced by Senators Whitehouse and Schatz in 2014, proposes a carbon fee starting at \$42 per ton in

¹⁴ The judge finalized his decision in September and neither BLM nor Arch Coal appealed the decision (Sierra Club, 2014).

2015. According to the accompanying press release, “The price of the fee follows the Obama Administration’s central estimate of the ‘social cost of carbon,’ the value of the harms caused by carbon pollution including falling agricultural productivity, human health hazards, and property damages from flooding.”¹⁵ Introduced in the lame duck session of the 113th Congress, the bill did not generate widespread public debate. Notably, however, at least some conservative commentators accepted the linkage of the fee to the SCC, but emphasized that because of interactions with the rest of the tax system, leakage, and without future international coordination the optimal tax would be less than the SCC (Murphy, 2014). In this aspect at least, the public discussion echoes the academic literature which points out that in practice the optimal carbon tax depends not just on the external cost of marginal carbon emissions but on its implementation and how it interacts with the rest of the tax code.

III. IAMs: A Starting Point for Improving SCC Estimates or Fundamentally Flawed?

The central question of this symposium is whether IAMs constitute an acceptable basis for estimating the SCC or whether an alternative approach is needed. We break this question down into two pieces. The first, which we address in this section, is an assessment of the scientific shortcomings of existing IAMs and whether there is reason to think that these shortcomings will be addressed in a time frame consistent with the formulation of climate policy. The second piece of the question, which we address in the next section, is whether a better alternative exists in the context of the existing institutional and legal structure of climate policy formulation and implementation.

The paper by Weyant (forthcoming) in this symposium provides a detailed description and history of the evolution of IAMs over the past 30 years. What is clear from a reading of Weyant's paper as well as the survey of IAMs in Nordhaus (2013b) is that IAMs and their role in SCC calculations have helped focus the attention of researchers on key areas of scientific uncertainty that drive many of the results in SCC calculations. Given the complexity of modeling climate change and its interaction with the global economy, it is encouraging that the critically important areas of sensitivity can be narrowed down to a handful. Especially important are 1) equilibrium climate sensitivity; 2) damage functions; 3) treatment of catastrophic events; and 4) the discount rate. There are, of course, other areas where research progress would be quite valuable but these four areas stand out. As we think about the value of future research in each of these areas, we are struck by how fundamentally different these four areas are in terms of how optimistic we can be about pinning down our understanding of these key inputs.

¹⁵ <http://www.whitehouse.senate.gov/news/release/sens-whitehouse-and-schatz-introduce-carbon-fee-legislation>

Because the equilibrium climate sensitivity is the province of geophysical climate science, we stick to the economic focus of this journal (and our own expertise) and focus on the final three issues in turn.¹⁶

Damage functions. The early damage functions in IAMs come from top-down cross-sectional analysis of the relation between the level of GDP and temperature, and thus associate warming with a shift in the level of future GDP, that is, a downward parallel shift in the path of GDP. In part because of the public importance of the SCC, current literature has undertaken a critical reexamination of these damage functions. Indeed disentangling temperature effects from other effects in top-down cross-sectional levels regressions faces significant identification challenges. As a result, this literature has focused on different identification strategies. One is to use short-run variation in the weather to examine effects on GDP growth; see for example Dell, Jones, and Olken (2012) and Deryugina and Hsiang (2014). Because weather variations are plausibly exogenous, after suitable conditioning on geographic variables, they allow estimates with greater internal validity than cross-sectional GDP regressions. On the negative side, the short-run nature of weather makes it challenging to analyze the effects of adaptation or to estimate with much confidence whether there are long-term effects on economic growth rates, not just levels, of weather or climate shocks. An alternative approach is to construct bottom-up estimates of damages. While a much larger undertaking than the top-down approach, a bottom-up approach is potentially amenable to more compelling identification strategies. For example, the property damage estimates in Koop et al. (2014) combined an insurance company compilation of built property values on the U.S. East Coast, elevation maps, and actual and simulated hurricane tracks to estimate the property damage cost of increased sea level rise and possibly stronger storms with more easterly tracks. Additional recent bottom-up research in the weather literature focuses on the effect of temperatures on labor productivity, health, crime, political unrest, and other elements of the total cost of climate change (see the survey by Dell, Jones, and Olken, 2014). And because the planet is now experiencing the early effects of climate change, new data are being generated that can be used to estimate damage functions, at least for the relatively small changes experienced so far. Most of the work in this area is quite new, the literature is growing very quickly, and the available data are expanding. All this makes us optimistic that this literature is on a path towards substantially better-identified estimates of damage functions in IAMs.

¹⁶ It is worth noting, however, that despite some 35 years of research, there has been little progress in narrowing the likely range of estimates of climate sensitivity (Weitzman, 2015).

Climate catastrophes. As discussed in National Research Council (2013), the Earth’s climate history suggests the existence of “tipping points,” that is, thresholds beyond which major changes occur that may be self-reinforcing and are likely to be irreversible over relevant time scales. Some of these changes, such as the rapid decline in late-summer Arctic sea ice, are already under way,¹⁷ while others, such as the release of methane from thawing Arctic permafrost, could reinforce GHG warming but are considered unlikely to occur in this century.¹⁸ The Weitzman (2009) dismal theorem focused the attention of the climate economics community on the potentially critical role of large-scale events that are abrupt on geological scale – so-called climate catastrophes – for formulating climate policy. The main thrust of the dismal theorem is that, with concave utility, society should be willing to pay substantial sums now to avoid worst-case catastrophic outcomes, what Pindyck (2011) and Weitzman (2011) have called “climate insurance.”¹⁹

This literature points to an important element of GHG emissions externalities being the possibility of worst-case outcomes. The challenge is how to turn this into a monetary value; as the review in the previous section indicates, a number (or a range of numbers) is in the end needed in the regulatory and political process. The Interagency Working Group’s estimate of the SCC does not explicitly model or account for climate catastrophes.²⁰ Because the climate catastrophe channel is largely distinct from the “local” damage function estimates arising from warming within the scope of human experience, a reasonable question is whether the climate catastrophe cost should be computed separately for the SCC, or whether it should be computed within IAMs. This is essentially a technical question on which we do not have strong views. If the two effects are additive, then separate computations could be justified, but this additivity would need to be demonstrated. Given the sensitivity of the “normal warming” estimate and, presumably, of the interaction between tipping points and the ECS, one can imagine that the two effects would not be additive. In any event, Weyant’s paper in this

¹⁷ Joughin, Smith, and Medley (2014) and Rignot et al. (2014).

¹⁸ National Research Council (2013).

¹⁹ The details of Weitzman’s theorem are sensitive to functional form assumptions but the broader point that risk aversion induces a willingness to pay a potentially large sum for insurance is not. See, for example Newbold and Daigneault (2009), Ackerman et al. (2010), Pindyck (2011, 2013), Nordhaus (2011, 2012), Litterman (2013), Millner (2013), and Weitzman (2011, 2014).

²⁰ While the Interagency Working Group modeled worst-case outcomes, and attempted to capture severe risks by reporting a high value of the SCC based on the 95th percentile value of the SCC drawn from a distribution of runs with a 3 percent discount rate, the analytical framework for those severe outcomes was obtained from large draws of the ECS combined with the standard IAM damage functions. Because those damage functions were calibrated from historical cross-country temperature comparisons they do not do justice to the mass extinctions, population disruptions, and land loss associated with some of the abrupt large-scale events such as the melting of the Greenland ice sheet.

symposium makes it clear that there is much research to be done before IAMs are capable of addressing catastrophic risk. Still, in our view it would be a mistake simply to focus on tail events given the likelihood of disruption to particularly vulnerable communities over the next few decades from climate change. The “normal warming” costs are still highly likely to be economically meaningful and are particularly salient.

Discount rates. Climate change involves damages that extend many hundreds of years into the future. While there have been advances in our understanding of long term discount rates on the order of a century (see, for example, Giglio, Maggiori, and Stroebel, 2014) it is not clear that an appropriate framework exists for empirically identifying discount rates over the several centuries used to estimate the SCC. One then has two choices: use existing data and – with some assumptions – adapt results to a time span that is an order of magnitude longer than the span over which estimates were made, or adopt an explicitly ethical and normative perspective, along the lines of Stern (2007). Neither approach is entirely satisfying, and our reading of the literature is that it is unresolved on basic issues, such as whether to use market rates, consumption-based (Ramsey) discounting, whether discounting should be horizon-dependent, or whether a normative approach should be adopted. To us, it seems that these basic issues reflect fundamentally different perspectives or philosophies and it is hard to see how debates over discount rates will be resolved soon.²¹

These observations suggest that uncertainty in the three key areas of damage functions, climate catastrophes, and discount rates is likely to persist, so that estimates of the SCC will continue to exhibit considerable uncertainty over the foreseeable future. One could interpret this conclusion as implying that IAMs should be abandoned for some other method for estimating the SCC, but we interpret it differently. Uncertainty is rife in economic and scientific research; after all that is why new research is undertaken. While the current vigorous research in these areas is unlikely to result in a lasting consensus on the right damage function, for example, it is reasonable to expect that this research will serve to characterize, and in some cases tighten substantially, the range of technical uncertainty associated with these and other issues within IAMs. With a better quantification of uncertainty, one that is based on ongoing research, the IAMs can better serve to quantify, and we think narrow, the range of uncertainty of the SCC as well as provide an increasingly solid scientific basis for the various steps in the

²¹ For various perspectives on discounting see Nordhaus (2013a), Arrow et al. (2013), Litterman (2013), and Barro (2015).

calculation. The idea of abandoning IAMs as the basis for the SCC, just as a burgeoning body of research promises to improve them and their measures of uncertainty, strikes us as misguided.

IV. The SCC as a Process, not a Number

Given the scientific uncertainty inherent in the current generation of IAMs, should the IAM-based SCC be replaced, as Pindyck (2013) has suggested, with another approach? We can think of at least five alternative approaches to that taken by the Interagency Working Group. We assess these alternatives using the five criteria laid out in the introduction: using the best available science and quantifying uncertainty; transparency, replicability, and comprehension; being subject to expert review and regular updating; providing guidance for ongoing research; and not being arbitrary and capricious and isolating the process from political pressure.

The first alternative approach would be to say that scientific work is so incomplete, and uncertainty so vast, that the Government simply should not use a SCC until more research is completed. We consider this position to be indefensible: while there is debate over how large the SCC is, the overwhelming evidence is that the costs of climate change are real and significant and that whatever the true value of the SCC is, it is not zero. Using a value of zero in cost-benefit analysis would restrict climate regulations to ones justified solely by their co-benefits. Because it is inconsistent with the best available science, abandoning the SCC because of uncertainty has already been rejected by the courts as arbitrary and capricious, as discussed above.²²

A second alternative is to drop an official SCC but to allow agencies to provide their own individual SCCs and thereby comply with the court requirement for an SCC. This alternative also is a step backwards and fails in multiple dimensions, including transparency and being explainable. The inherent redundancy also makes it administratively complex, less likely to use the best available science, and a poor use of limited government resources.

A third alternative to constructing an official SCC for policy purpose takes a "revealed preference" approach. Policy design in a number of political jurisdictions has led to a cost of carbon

²² A more nuanced version of this argument is that uncertainty about a model, or about key policy parameters (such as the SCC), could warrant taking a conservative approach to its implementation. Brainard (1967) provided an early articulation of this view in the context of monetary policy, suggesting that uncertainty would lead to caution when the policy has costs. Brainard's (1967) result is special, however. Giannoni (2002), for example, considers a monetary model in which optimal policy guards against particularly bad models by responding more aggressively to shocks, not less, than when there is no model uncertainty; also see Hansen and Sargent (2007) and Cai, Judd, and Lentza (2013). In any event, this more nuanced argument does not imply biasing the estimate of the SCC towards zero, rather it concerns whether the policy path should be more conservative or more aggressive in the face of uncertainty.

being implicitly or explicitly mandated. Examples include British Columbia's carbon tax, California's cap and trade system, the EU's emissions trading system, and South Korea's recently enacted cap and trade system. The official SCC would then be some average of a selected set of existing programs under the theory that the policy process has chosen the socially appropriate SCC. This approach has the virtue of being explainable – the U.S. is just following suit – and could be updated when other jurisdictions change their SCC. But it fails on most of the other criteria, such as using the best available science, being subject to peer review, conveying uncertainty, and providing guidance to researchers for further improvements. Indeed, this approach only works under the heroic assumption that the political process manages to absorb the relevant scientific evidence while ignoring all costs of mitigation, especially those falling on politically important interest groups. A political revealed preference approach seems quite unlikely to approximate the true SCC.

A fourth alternative is that the U.S. government would construct and maintain its own official integrated assessment model for U.S. policy purposes, instead of using (as did the Interagency Working Group) leading peer-reviewed models. This might be done, for example, by adding models of the physical processes in the ocean, atmosphere, and land cover to existing modules in the Energy Information Administration's annual integrated energy market model, the National Energy Modeling System (NEMS), and by enhancing the NEMS international energy activity module. The advantage of this approach is that there would be "in-house" modeling capabilities and expertise within the Federal government to build and maintain the model and to improve it as new research and insights into climate change emerges. If properly implemented and funded, this approach would do well by many of the five criteria, including using the best available science, quantifying uncertainty, periodic updating, external review, and providing guidance to researchers. The disadvantage, however, is that expertise would have to be built up within the federal workforce to build the model and there is no assurance that sufficient capacity would be in place to carry out such an ambitious undertaking and to keep up with scientific developments. Perhaps more important, it is not clear that a federal IAM would be sufficiently transparent and explainable that the public would have confidence in making policy from that model only; in the end, this alternative has the Federal government making myriads of modeling judgments which will inevitably be viewed as subject to political influence. While the NEMS model has high credibility, the NEMS modeling judgments (such as how best to aggregate time periods and electricity generation regions) to balance output detail against computational feasibility are far less controversial, and have far less reaching ramifications, than the judgments involved in building a climate damages module for different regions of the world. And in the end an in-house model could be subject to political

pressure – or appear to be subject to pressure – even if it were housed at an independent agency or a national laboratory – through the budget process which necessarily reflects the political positions of the Executive Branch and Congressional appropriators.²³

The fifth approach, which is proposed by Pindyck in his paper in this symposium and in Pindyck (2013), is to base the SCC on expert judgment. For example, the U.S. Government could contract with the National Research Council to constitute a standing panel of experts which would deliberate on the SCC, reach an initial estimate, and convene again every five years to consider whether a new SCC value is warranted based on how the judgment of the members has evolved in the interim. If implemented properly, this process could be based on the best available science as interpreted by the experts, it would entail regular updating, the experts could convey their judgment both of the SCC and its quantified uncertainty, and the experts could convey their views to researchers about what additional research is needed. But in our view this proposal falls short on the other criteria, especially if (as Pindyck's proposal would, it seems, have it) there is a side constraint that the experts are prohibited from using IAMs. If the experts are not allowed to use IAMs, then that presumably would disqualify many experts who have devoted much of their careers to developing IAMs, since their expert judgments would be heavily informed by the IAMs on which they have labored. Presumably those experts who focus on climate catastrophes/climate insurance calculations would also be precluded from using IAMs, which close off one line of quantifying that insurance value. One suspects that some of these experts would object to these preclusions which they would feel, in their expert judgment, are not scientifically warranted: Excel is OK, DICE is not? In any event it is hard to see how a panel of experts, precluded from using a class of models, would result in an estimate that is transparent, replicable, and uses the best available scientific information. Moreover, as a practical matter, it is hard to see how a judgmental expert panel would not be subject to political influences, since a standard institutional practice is to balance panels of experts not by weighting by scientific credibility but by ensuring representation of a spectrum of views. And – at the risk of being accused of practicing law without a license – it is also hard for us to see how a panel-of-experts approach, with the side constraint of not using a class of scientific tools, would be viewed by the courts as other than arbitrary and capricious.²⁴

²³ An official government model would also go against the norm of using the peer reviewed literature in regulatory impact analysis rather than independent government analysis. We thank Joe Aldy for pointing this out.

²⁴ Pindyck's argument is based in part on his view that the panel should focus only on catastrophic risks. We argued above that the research on non-catastrophic damages is steadily improving and that damage functions are increasingly calibrated to real-world data. Another argument for focusing on non-catastrophic risk is the need in the international climate negotiations to demonstrate credibility about developed country concerns with near-

In the end, each of these alternative approaches fails to meet many of our five procedural criteria. As the discussion of the panel-of-experts approach makes clear, we find it hard to imagine a successful process for estimating the SCC that does not involve the use of IAMs. The science behind climate change is extraordinarily complex and the interaction between the climatic and economic outcomes calls for the use of both physical and economic models. This is the very essence of IAMs. To us, it is unescapable that integrated modeling must play some role in the analysis.

What about the process followed by the Interagency Working Group? In our view, that process does reasonably well on the five criteria, but room remains for further improvement. Conditional on the models, the computational approach is straightforward and follows from economic and statistical principles. One can always argue with specific modeling choices the working group made. In particular weighting the three models and different economic scenarios equally in its averaging suggests all models/scenarios have equal credibility. The difference across the models is, however, so striking that it begs expert review and judgment of these models (and other potential models for consideration in the process) to put appropriate weight on whichever models are included in the analysis.

Setting aside issues of weighting model runs, the process itself is scientifically sound. The process itself is transparent and readily understandable given the care with which the 2010 Technical Support Document was written, and the rarely-satisfied Government Accountability Office (2014) found the process to be consistent with federal standards for internal control. As a by-product of the results it reported, the Interagency Working Group made clear the importance of key parameters, most notably discount rate, distribution of ECS, and damage function choices. This gives useful feedback to the research community.

But we believe the process has room for improvement on three related criteria. First, the Technical Support Document indicates that the estimate will be reviewed from time to time as new science becomes available, but there is no explicit process for that review and for the production of new estimates. Second, while there have been multiple opportunities for the public to comment officially on the SCC and the Technical Support Document, there is no formal framework for external expert review. Third, although the Interagency Working Group made several decisions that protected it from political influence,²⁵ the process is organized by the Executive Office of the President and, regardless of whether

term damages to the most vulnerable developing countries. A social cost of carbon process that ignored non-catastrophic damages would undermine on-going efforts to build and sustain that credibility.

²⁵ For example, although the Interagency Working Group was headed by the Executive Office of the President through the Council of Economic Advisers and the Office of Management and Budget, it mainly consisted of numerous agencies representing disparate interests and expertise. The decision to use leading peer-reviewed

there is in fact political influence, the process is likely to retain the perception of political influence. These issues are addressed by the recommendations of Pizer et al. (2014), who suggest a regular revision schedule (e.g. every 5 years); that the process should be similar to the interagency process used for the 2010 and 2013 analyses; that the estimates should be regularly reviewed by National Research Council, a branch of the National Academy of Sciences; and that the process should be codified through an Office of Management and Budget (OMB) memo or circular. We agree with these recommendations, which would transform the SCC from being a single number, or snapshot of the research, into a stable process for revision. It would be essential that the expert scientific review be coordinated so that NRC recommendations can be incorporated into the subsequent updating process. In addition to enhancing transparency, providing expert review, and providing guidance for further research, regular oversight by the National Research Council provides additional protection from political influence since attempts at political influence would presumably be called out by the review panel. Still, an issue that could be explored is whether additional steps are warranted to further protect the process from political influence, for example housing the technical work associated with the models at a national laboratory or an independent agency such as the Energy Information Administration.

V. Conclusion

These remarks lead to several conclusions. Given its importance in regulatory implementation and the public debate, an official SCC must be as credible as possible; we propose five criteria aimed at ensuring that credibility. To the point of this symposium, the SCC must have a numerical value and be associated with numerical measures of uncertainty, and we cannot see how that can be done credibly without sophisticated computer models that incorporate climate and economic considerations, that is, without IAMs. Complicating all this, the horizon over which the uncertainty surrounding the costs of climate change is resolved extends beyond the horizon in which climate policy decisions must be made, and moreover estimates of the SCC will change as new science becomes available. These conclusions imply climate policy must be sufficiently sophisticated that it can adapt to evolving science and evolving estimates of the SCC. This will require a challenging degree of sophistication in climate policy.

To date the SCC has been used in ways that are important but, to the best of our knowledge, its numerical value has never been determinative for major regulations. The cost-benefit analyses for energy efficiency regulations typically find them justified from the energy savings alone, and in the

models instead of just one model, or an internally-developed model, also provided a layer of insulation from political influences.

largest rule in which the official SCC has been used, the EPA's Clean Power Plan, the rule would have positive net benefits even if the SCC were zero given the health co-benefits of reducing particulate emissions. For these applications of the SCC so far, climate benefits have been secondary. But, as the Whitehouse-Schatz carbon fee bill makes clear, the SCC must be able to stand on its own as a measure of the price of carbon in meaningful market-based policies for reducing GHG emissions. It is hard to see how that can happen without sophisticated integrated frameworks for computing marginal climate damages, that is, without IAMs. The task, then, of the research community is to continue the exciting and important new work on improving our understanding of climate damages, large-scale abrupt geophysical changes and their economic consequences, and long-term discount rates.

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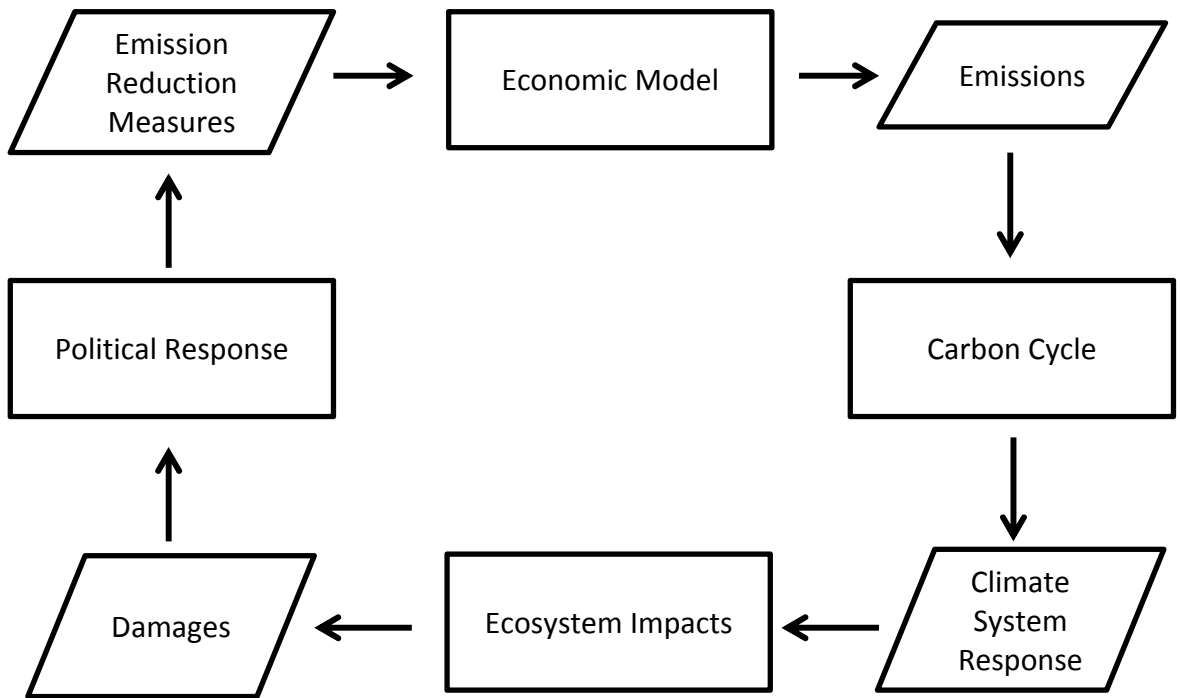


Figure 1. Integrated Assessment Model Schematic

**Table 1. Indicative Damages from Greenhouse Gas Emissions:
NRC Study**

	Damages from Climate Change	
Discount Rate	Relatively Low	Higher
1.5 percent	10	100
3.0 percent	3	30
4.5 percent	1	10
Source: NRC (2009)		

Table 2. Interagency Working Group SCC Estimates

Discount Rate Year	5.0% Mean	3.0% Mean	2.5% Mean	3.0% 95 th Percentile
2020	\$7	\$26	\$42	\$80
2020(rev)	12	43	64	128
2050	16	45	65	136
2050(rev)	27	71	98	221
Source: Interagency Working Group (2010, 2013). Table reports estimates of the social cost of carbon measured in 2007\$ per metric ton. "rev" indicates revised estimates from the 2013 technical update.				