ENVIRONMENTAL LAW • INSTITUTE®

POLICY BRIEF

WORLD RESOURCES INSTITUTE

MORE THAN MEETS THE EYE
The Social Cost of Carbon in U.S. Climate Policy, in Plain English

RUTH GREENSPAN BELL AND DIANNE CALLAN

SUMMARY

Presidents since Ronald Reagan have required that significant rules issued by the federal government be accompanied through intra-governmental review by a cost-benefit analysis. In addition, the Obama administration (like the Bush administration before it) has imposed a requirement to assess climate regulation through the lens of a figure (or range of figures) known as the "social cost of carbon" (SCC). The SCC estimates the benefit to be achieved, expressed in monetary value, by avoiding the damage caused by each additional metric ton (tonne) of carbon dioxide (CO_2) put into the atmosphere.

The impact of SCC numbers is not theoretical and has consequences for the government regulatory process and therefore for the strength of regulations on climate change that emerge from it. Application of this tool can be problematic to achieving optimum outcomes for society.

A growing literature indicates that developing the SCC requires assumptions that go well beyond the usual boundaries of science or economics. It requires many judgment calls that are hidden in complex economic models and largely invisible to policymakers and stakeholders.

The Obama administration has formulated a standardized approach to estimating the SCC for all new federal rules issued that would regulate greenhouse gases. In the case of climate change, the government calculates the cost imposed on society globally by each additional tonne of carbon dioxide (CO_2), the main greenhouse gas. These include health impacts, economic dislocation, agricultural changes, and other effects that climate change can impose on humanity. The benefit to society of avoiding those costs is summed up in the social cost of carbon.

In 2009 an interagency team of U.S. government specialists, tasked to estimate the SCC, reported a range of values from $5 to $65 per tonne of carbon dioxide. The choice of a final figure (or range of figures) is, in itself, a major policy decision, since it sets a likely ceiling for the cost per tonne that any federal regulation could impose on the economy to curb CO_2. At $5 a tonne, government could do very little to regulate CO_2; at $65, it could do significantly more. Higher SCC numbers, such as the United Kingdom's range of $41–$124 per tonne of CO_2 with a central value of $83,[1] would justify, from an economics perspective, even more rigorous regulation.

This paper discusses the limitations that the special nature of climate change imposes on cost-benefit analysis and its constituent parts, primarily focusing on the estimation of the SCC. It explains in plain English the various steps in calculating the SCC, the weaknesses and strengths of those calculations, and how they are used to inform climate policy. The aim is to help policymakers, regulators, civil society, and others judge for themselves the reliability of using the resulting numbers in making policy decisions. Framed as a series of questions and answers, it also allows these stakeholders to understand the current debate within the economics community as to whether climate policy is a special case for which standard cost-benefit and SCC tools of the trade are not adequate to assess policy options.

Environmental Law Institute
2000 L Street, NW, Suite 620
Washington, DC 20036
Tel: (202) 939-3800
www.eli.org

World Resources Institute
10 G Street, NE, Suite 800
Washington, DC 20002
Tel: 202-729-7600
www.wri.org

July 2011

Introduction

As the U.S. federal government uses its rulemaking authority to address greenhouse gas emissions, it is important to understand the social cost of carbon (SCC) and its role within the process. When the federal government considers regulation, many values are at play, and the process engages various expertise including law, climate science, engineering, economics, and public policy as well as reaching out to consider the views of stakeholders. SCC provides a dollar figure, or range of dollar figures, that estimate the value of social benefits accrued by acting to reduce climate change. Because of the internal government process for evaluating proposed regulations, the SCC dollar figure, which is a tool devised by economists, can have significant impacts on decisionmakers if they approach regulation from the point of view that the *cost* per tonne to curb CO_2 should not be greater than its presumed *effectiveness* in achieving the result. The SCC value can also be misused if the limitations and caveats inherent in its estimation are not considered.

This paper takes no direct position on the merits of using cost-benefit analysis or estimating the social cost of carbon. Instead, it seeks to give non-economists a basic understanding of why and how SCC is calculated and to raise important points about its use, limitations, and assumptions.

Box 1 — **Carbon, CO_2, or Greenhouse Gases?**

Since many different greenhouse gases of varying strengths contribute to climate change, scientists use the concept of CO_2 equivalent (CO_2 –eq) to sum their climate change impacts. In calculating the CO_2 –eq, scientists also consider timescale because various greenhouses gases differ widely in their persistence in the atmosphere. However, in making the calculation of social cost of carbon, U.S. regulators as of mid-2011 have considered only the effects of regulating CO_2, largely because of a lack of data on compound-specific impacts of climate damages (although efforts have been undertaken to expand the scope beyond just CO_2).[1,2] CO_2 alone accounts for roughly 70% of the climate effects from greenhouse gases.

Notes

1. Alex L. Marten and Stephen C. Newbold, *Estimating the Social Cost of Non-CO_2 GHG Emissions: Methane and Nitrous Oxide* (U.S. EPA National Center for Environmental Economics, Working Paper No. 11-01, 2011).
2. U.S. Dept of Energy, Final Rule Technical Support Document: Energy Efficiency Program for Commercial and Indus. Equipment: Small Electric Motors, Appendix 15A. Social Cost of Carbon for Regulatory Impact Analysis under Exec. Order 12866 13 (Mar. 9, 2010) [hereinafter IWG Report], *available at* http://www1.eere.energy.gov/buildings/appliance_standards/commercial/sem_finalrule_tsd.html.

1. What Is the Social Cost of Carbon?

The SCC is an estimate of the monetized damages associated with an incremental increase in greenhouse gas emissions in a given year. Another way of saying this is that the SCC is a measure of the benefit of reducing greenhouse gas emissions now and thereby avoiding costs in the future. As a very simple example, if emissions damage coral reefs, which in turn discourages tourists from visiting Australia, one cost incurred will be lost revenue to the tourist industry. Avoiding that cost is a benefit.

When economists seek to estimate the SCC, they must find a way to estimate the physical and human damages caused by CO_2 emissions and the resulting climate change. This enters the realm of scientists researching how growing greenhouse gas emissions are likely to affect the climate system. Climate scientists endeavor to understand a wide variety of harms that can range from more frequent extreme weather events to changes in normal, local climate patterns, to the direct and indirect consequences of ice-free summers in the Arctic.

Economists do not second-guess the scientists. But they do pick and choose among the latter's many estimates, making judgments about which to include in the economic modeling of damages, and funneling the climate science through their own methods of modeling the world. As explained in more detail in Section 4, SCC estimates are calculated by taking—or trying to take—into consideration learning from climate science about a wide variety of factors such as net agricultural productivity loss, human health effects, and property damage from sea-level rise and changes in ecosystems. Economists fit some subset of these factors into one or more "integrated assessment models" (IAMs), as described later in this paper, to provide a single consistent framework for evaluating a total system response to rising carbon dioxide emissions, including interactions between various component parts of the various dynamic human and environmental subsystems.[2]

Regardless of the modeling approach, a fundamental challenge to this enterprise is uncertainty. Scientists cannot definitely state that certain pollution levels will lead to particular impacts, which means that the consequences for humans could be much less or much more severe than the median estimate. For example, the loss of a forest to pine-bark-beetle infestation removes those trees from their role in sequestering carbon dioxide and purifying air, but the root system from the same forest might also have been helping to filter and clean water used by downstream human populations, or might have prevented landslides. In addition, the forest might have harbored vegetation used in medicines. The total loss in this example is not simple; a single loss (i.e., the loss of forest) might lead to multiple unexpected effects (i.e., air-quality impacts, loss of clean water, and future landslides), the nature and cost of which we are currently uncertain.

2. Why Estimate the Social Cost of Carbon?

Executive Orders since 1981 have required that proposed federal regulations undergo review by the White House's Office of Management and Budget (OMB) prior to being proposed and prior to adoption.[3] For "significant rules", the review must be accompanied by a formal Regulatory Impact Analysis (RIA). One required part of the RIA is a Cost-Benefit Analysis (CBA), which attempts to gauge whether a particular regulation is economically efficient by looking at the benefits (in economics language, the avoided costs) relative to the estimated costs of complying with the regulation.

The Office of Information and Regulatory Affairs (OIRA) within OMB manages the two-stage review process, acting essentially as traffic cop, with the authority to send a regulation back to the agency for revisions or reconsideration when the regulation is deemed not to "comport with the Executive Order's principles and the President's priorities."[4]

Broadly, the SCC informs policymakers from a cost-efficiency point of view how stringent to make regulations, by providing them with a figure that purports to estimate the monetary value of the damages caused by each additional tonne of CO_2 put into the atmosphere. In the review of federal regulations involving greenhouse gas emissions, the SCC estimates the benefits side of the cost-benefit equation. From that perspective, to conserve limited resources, society as a whole should not pay any more for these restrictions than is justified by the benefits received from compliance with the regulation. Thus, regulators seek to determine whether greenhouse emission standards for cars, which might cost $10 per tonne of reduced emissions, for example, will bring about benefits from reduced emissions that are worth that cost or more.[5]

Given the importance placed on the economic efficiency of regulatory decisions, the social cost of carbon could have a major impact upon the U.S. government's approach toward combating climate change.

3. How Does the SCC Influence U.S. Government Policy Decisions?

The SCC estimates used by the federal government before 2009 were expressed as a range of numbers, and not applied consistently. Different values were used in different rulemakings, even within the same agency.[6] For instance, the Department of Energy in a 2008 regulation of air conditioners and heat pumps estimated that the SCC was in the range of $0 and $20 per tonne but then failed to include this estimate in its cost-benefit analysis, arguing that the proposed regulation passed a cost-benefit test regardless of the SCC.[7]

In 2009, the Obama Administration created an interagency working group (IWG) to standardize the estimate of SCC to be used across federal agencies as they conduct Regulatory Impact Analyses.[8] The working group included the EPA, the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury, and six other federal bodies.[9] Using modeling developed by economists and other analyses and tools described in detail in the following sections, the IWG panel report recommended a range of SCC values—$5, $21, $35, and $65 (in 2007 dollars)—per tonne of carbon dioxide with the intent that these values be used in individual rulemakings across government involving the regulation of CO_2.[10] $21 is the "central number" and carries the most weight in analysis.

So far these SCC values have been used in the Regulatory Impact Analysis for DOT/EPA rules imposing miles-per-gallon automobile fleet standards (CAFE) and Department of Energy regulations concerning energy efficiency standards.[11]

The interagency working group produced a range of numbers to reflect the fact that numerous important judgments must be made to calculate the SCC for any given rulemaking. The first three values reflect the use of three different discount rates (as discussed below, the choice of discount rate is controversial; the IWG sidestepped the issue by using three); the fourth shows the cost of worst-case impacts.[12] The IWG does not instruct federal agencies which discount rate to use, suggesting $21 per tonne of CO_2 as the "central" value but emphasizing "the importance of considering the full range."[13]

To put the U.S. numbers in perspective, when the U.K. government last calculated the SCC in 2009[14], its analysis yielded a

Box 2 The Stern Review

In 2006, the U.K. government released a report from Sir Nicholas Stern, the Head of the Government Economic Service and former World Bank chief economist. The influential report reviewed the potential impacts of climate change and the economics of climate policy. Although its scope was much more wide-ranging than that of U.S. efforts to calculate a social cost of carbon, the report did include an estimated central number social cost of carbon of $85 per tonne of CO_2.[1] The reasons for the wide disparity between SCC calculations are discussed in Section 4.c below.

Note

1. Nicholas Stern, The Economics of Climate Change xiv, 287 (2007). $85/tonne is the Stern review number based on business-as-usual projections, year 2000 prices. *Id.*

Box 3 Optimal Carbon Price or Shadow Price

In an estimation distinct from the SCC, economists may also try to calculate the optimal carbon price to achieve a given policy objective. In the economists' toolbox, this reflects a preference to use price (for example, a tax rather than direct regulation) to reduce society's use of carbon dioxide. The model on which they work is the "rational economic actor"—someone whose actions are predicated on weighing the relative costs and benefits of different options and making a choice entirely based on these values (other relevant values reflecting other perspectives might include ethics, science, or political feasibility). Thus, they ask: what is the optimal price to change behavior—the rate that would cost the economy no more in reduced productivity than the climate damage it would prevent. Estimates of the Optimal Carbon Price are being deployed by U.K. decisionmakers who want to understand how much it will cost to reduce a tonne of carbon dioxide *to the levels their policy requires*. This is a similar exercise to determining the price that carbon should trade at in carbon markets. The United Kingdom has shifted to this approach and away from the SCC because domestically, and as part of the European Union, it is committed to achieving 20% GHG reductions below 1990 levels by 2020.[1]

The United Kingdom has a clear policy objective and is estimating the costs and benefits of carrying it out. In contrast, the United States has no official greenhouse gas emissions reduction requirements (except for the presidential commitment made in Copenhagen to reduce emissions 17% by 2020) and must justify action, regulation by regulation, based on cost-benefit analysis, using the SCC.

Note

1. The U.K. government pledged in May 2011 to adopt a carbon budget of 50% emissions cut averaged across the years 2023 to 2027, compared with 1990 levels, but this has yet to be enshrined in law.

range of $41–$124 per tonne of CO_2 with a central value of $83.[15] The U.K. analysis used very different assumptions, including a much lower discount rate. Their resulting central value supports regulation four times as stringent as the U.S. central value.

In other words, the impact of the IWG's 2009 SCC calculation on federal policy and U.S. climate actions is substantial. With an SCC estimate of $21, only rules that, when implemented, would cost less than $21 per tonne of CO_2 reduced would be considered economically efficient. Economists Frank Ackerman and Elizabeth Stanton of the Stockholm Environment Institute point out that the U.S. central SCC number in 2010 translates to roughly 20 cents per gallon of gasoline, in their view "far too small a price incentive to prompt substantive mitigation measures."[16]

4. How Is the Social Cost of Carbon Estimated?

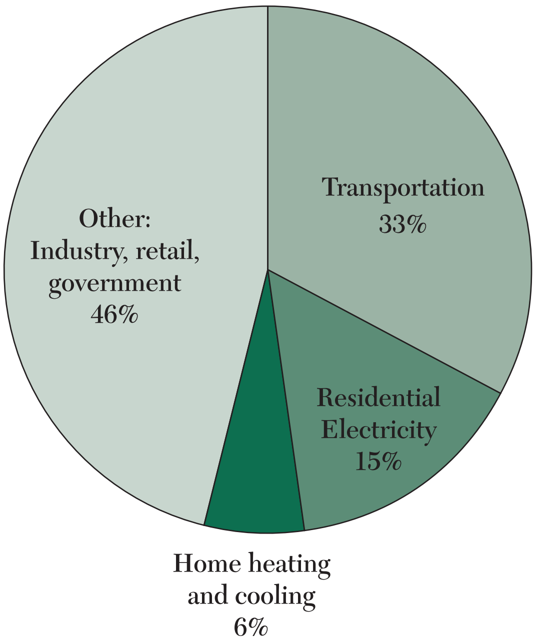
The SCC is estimated using complex economic models that seek to mimic or approximate the real-world factors that impose both costs and benefits on society, and thereby to examine the economic processes at play. The basic unit of emissions for the SCC calculation is a metric ton (tonne) of CO_2.[17] U.S. residents emitted on average 21 tonnes of CO_2 per person in 2005, as shown in Figure 1.[18]

Across the United States, one tonne of CO_2 is emitted, *on average*, by:[19]

- a family car every two and half months;
- a household's use of heating and cooking fuel every four months (if energy use were spread equally throughout the year and throughout the country);[20]
- a household's use of electricity every six weeks;
- a microwave oven in typical use for seven years or a refrigerator for 15 months.

These are only a small sampling of the vast array of human activities that contribute to GHG emissions. Given their ubiquitous nature, efforts to reduce GHG emissions will impose costs on society, the extent of which is debated. These include the price of new energy technologies and more efficient appliances, vehicles, and heating and cooling systems, as well as the costs of replacing or upgrading existing infrastructure (for example, to replace or retire coal-burning power plants). Some households may face higher electricity bills; drivers may face higher costs of transportation and decide to switch to alternative forms of transport.

FIGURE 1 Percentage Emissions per U.S. Resident, by Sector, 2005



These changes will also produce benefits (and can be considered investments in energy productivity). As noted earlier, economists define the benefits of reducing GHGs in terms of the avoided damages to be incurred from climate change in the future and estimate the social cost of carbon accordingly.[21]

For non-economists, this can be hard to grasp. Some of the real-world costs avoided are relatively obvious, although perhaps difficult to translate into monetary damages. These include increasingly more intense floods and droughts, which are producing corresponding increases in damage and costs, as recorded by the insurance industry. However, since there have always been floods and droughts, the challenge is to estimate which of these can be connected to a changing climate. Where it gets even harder is to identify and monetize the potential wider, ripple-effect consequences of extreme weather events such as famine, dislocation, mass migrations, civil instability, potential conflicts, and wars. How can one price loss of life, or cultures, such as those of small island states, that might be displaced and possibly made extinct?

As discussed below, economists estimating these numbers must, by necessity, simplify representations of impacts. Often, they must use a proxy, which may not adequately calculate the real harms being inflicted. For example, it is easier to assume that temperature rises equally around the globe, even though there will be differences geographically; or that there will be a rise in average temperatures, rather than calculating the number of days above a temperature threshold and its potential impact for some major crops.[22]

a. How do the SCC Models Work?

The particular models used for calculating SCC are called "integrated assessment models" (IAMs). They attempt to incorporate knowledge from a number of fields of study, such as engineering, technology, behavior, and climate science, with the ultimate purpose of deciding whether particular climate change policies are economically efficient in the context of a cost-benefit analysis. The IAM uses mathematical formulas to simulate the relationships between economic activity, measures to control emissions, and the desired environmental outcomes. In so doing, it facilitates the estimation of benefits (the SCC) as well as the comparison of the costs and benefits of emission changes in monetary terms.

The three models most prominently used by mainstream economists and by the U.S. government's interagency working group to estimate social cost of carbon are DICE,[23] PAGE,[24] and FUND.[25] Although there is some overlap between these models, each uses its own methods to import the climate science to make estimations of "climate damage functions." The "climate damage function" is shorthand for estimating the relationship between CO_2 emissions and the damage caused, in order to approximate how future damages might be reduced if CO_2 emissions fell.

Each modeler selects his or her own method to represent each of the relevant factors. This requires many simplifying assumptions.[26] For example, it is common for models to simply represent global climate change as an increase in global or regional average temperature. The more accurate, but harder to implement, alternative would be to try to capture in the model every detail of expected change in the climate system, and the consequences of those changes. In other cases, modelers make a variety of assumptions about the severity of the damages from changing weather, trying to approximate details of the dynamic process whereby natural systems interact on Earth and the way carbon-cycle feedbacks have been distorted by anthropogenic GHG emissions.

Making such approximations is difficult. The carbon cycle, for example, naturally operates in a relatively balanced state, with seasonal shifts moving carbon from the land to the atmosphere

Box 4	IAMs and their Application Explained

"The user enters a set of economic parameters, including pre-existing baseline projections of economic growth and technological improvements, developed within the standard economic literature. These projections include predictions of future greenhouse gas emissions, which are a function of GDP and a society's 'carbon intensity': the amount of carbon a nation's economy must generate in order to produce wealth.

"From these projected emissions, the climate models predict changes in the concentration of greenhouse gases in the atmosphere. These . . . are in turn used to predict changes in temperature, and the models then project economic harms (in the form of diminished worldwide GDP) from the expected temperature increases . . . .

". . . In order to generate values for the social cost of carbon, the Interagency Group ran the PAGE, DICE and FUND models using standard baseline projections of economic growth and technological development . . . and determined the models' predicted effects of warming on GDP . . . . The Group then re-ran the same models using the same baseline projections, but with *one additional ton of carbon emissions*, in order to determine the marginal effect on global GDP of that additional unit of carbon. . . . [This] is the social cost of carbon: the amount of money saved for every marginal ton of atmospheric carbon that is *not* emitted."[1]

Note

1. Jonathan S. Masur & Eric A. Posner, *Climate Regulation and the Limits of Cost-Benefit Analysis* (John M. Olin Law & Econ., Working Paper No. 525, Pub. Law and Legal Theory, Working Paper No. 315, 17 (August 2010), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1662147##.

and then back again. The ocean acts as a buffer, one that can readily take up or release carbon, depending on the circumstances. However, with the rapid rise in CO_2 emissions, as a result of human activities, the balance has been significantly disrupted. Ocean and land carbon sinks (also known as reservoirs) cannot absorb all the excess levels of CO_2, leading to rising concentrations in the atmosphere. Dynamic carbon-cycle feedbacks can occur naturally or as a result of human influence affecting the flow of carbon between the different reservoirs. For example, because gases are less soluble in warmer liquids, rising ocean temperatures may have the effect of slowing the rate at which the ocean can take up CO_2 from the overlying air, leaving more CO_2 in the atmosphere, which, in turn, raises air temperatures and heats the ocean further.

Each of the IAMs tries to capture the carbon cycle, but with its own approach to distilling the particular physical phenomena into manageable bites for the model to digest.

DICE assumes fixed rates of flow between major carbon-system reservoirs (ocean, atmosphere, and biosphere) and then totals impact estimates for six sectors into an aggregate global estimate of damages. DICE also tries to account for unpredictable but possible abrupt climate changes. These might include, for example, a shutdown of ocean currents responsible for warming or cooling coastal regions of the continents, large-scale melting of ice sheets leading to dramatic ocean level rise, or the rapid release of methane from arctic permafrost regions, which would further accelerate warming.

PAGE relies on reports from the IPCC. PAGE—and FUND—attempt to capture the uncertainty of the science using a technique called Monte Carlo analysis.[27] Its designers try to build into the model the possibility that climate scientists have either under or overestimated the impacts. They use probability distributions (laypeople might understand this as essentially a Bell curve, although there is theoretical work underway examining whether the Bell curve is an appropriate way to describe the probabilities) as a way of systematically addressing the likelihood of each effect happening. The 2002 version of PAGE assumes a 1% chance of catastrophe, such as the melting of a major ice sheet, should global temperatures rise above 2 degrees C (3.6 degrees F) compared to preindustrial levels. A newer version assumes a 10% chance of catastrophe for the same threshold.[28]

FUND includes sector- and region-specific calculations of damage to agriculture, forestry, water resources, energy consumption, sea-level rise, ecosystems, and health. FUND does not take abrupt, catastrophic changes such as those outlined above into consideration.

It is beyond the scope of this guide to provide detailed comparisons of individual models, the factors they consider, and how each approximates the potential damages from climate change. Moreover, models are constantly updated to increase their sophistication and to supplement the analysis.

However, important factors that all economic modelers should consistently take into account if they are to be faithful to the climate science include:

- the impacts of increased temperature from altering the balance of incoming and outgoing energy in the Earth-atmosphere system as a result of rising concentrations of greenhouse gases ("radiative forcing")

- possible cooling effects (for example, certain pollutants create a form of haze that reduces the warming impact of the sun although they have harmful impacts on human health)
- regional temperature effects (since, as noted, different parts of the Earth may react in different ways)
- the possibility that changes in the climate system occur in "nonlinear" ways via feedback cycles, tipping points, and/or cascading effects that are irreversible
- economic as well as environmental and social impacts[29]
- the possibility of humans engaging in adaptive measures to buffer or mitigate the impacts of an increasingly hotter world, for example, engineering agriculture to survive in changed environments

In sum, the models used by the federal government to estimate the SCC apply a variety of approaches to estimate the economic harms that might be caused by climate change, with each model adopting a unique approach. These models are not always transparent, may not take into account catastrophic climate change, contain many extrapolations and assumptions, and do not factor in all aspects of climate science. [30]

b. *How Accessible Are the Assumptions Contained in the Models?*

A further complication in understanding and comparing models is that in some cases, such as DICE, the authors have made the component parts, and the tools to run the model, publicly accessible, whereas others are proprietary.

Still other models are essentially black boxes because of their complexity and the obscure programming language used. For example, the FUND model, which is growing in acceptance as a standard for evaluation of climate economics, was until recently run only by the model's creator, Richard Tol, and his coauthors. A recent effort by a group of researchers to deconstruct the FUND model revealed many of the unique features that drive its outcomes.

Researchers learned, for example, that FUND assumes that agriculture can tolerate huge temperature changes. In the case of South America, FUND's 95% confidence interval[31] on the ideal temperature for crop production extends to a wide swing of 17 degrees C (30.6 degrees F) above and below historical levels. The model values cumulative damages including sea-level rise, storm damages, droughts and floods, human deaths and diseases, extinction of species, and forced migration of huge numbers of climate refugees at only $4 per tonne of CO_2, with water-supply problems and extinction of species accounting for $2 per tonne of CO_2. It excludes catastrophes, which could include the collapse of major ice sheets, accelerated methane releases from melting permafrost, collapse of rainforests, and drastic changes in ocean currents. Reasonable people could and do disagree with these conclusions. In other words, it is as important to understand the assumptions behind a model as it is to understand its final results.[32]

c. *How Do SCC Models Handle Complexity and Uncertainties?*

The world that models seek to simulate is highly complex. Consequently, many climate and economic change models are also complex, and many simplifying assumptions are required. Constructing these models is not a mere mechanical exercise. The modeler must make numerous judgments about real-world behavior and how to represent it within the model. The modeler must also distill the various elements down into equations in order to compare one against another[33] and to capture interactions between different component parts.

As the model cannot include every possible factor in either a real-world economy or a real physical world, the modeler must make judgments about appropriate levels of detail, which factors to include, and which to exclude. Likewise, because important aspects of human behavior and the Earth system are dynamic by nature, they are often unpredictable or difficult to represent accurately through the equations that make up models. Among the challenges in any modeling exercise (whether science or economics) is the possibility of surprises and how they interact with other factors. Paul Slovic, a leading researcher of risk perception, noted the difficulties of understanding the indirect consequences of an unexpected event. He analogizes this to a stone dropped in a pond, which causes ripples that expand outward to affect related areas.[34]

The degree of complexity of modeling to estimate the social cost of carbon is further exacerbated by the complexities of climate science, such as the potential for unexpected events (cascading effects, feedback loops, tipping points) that are largely unpredictable based on our current knowledge. Nevertheless, the SCC cannot be reliably calculated without making some attempt to understand the climate system and to estimate the possible impacts that changes to that system could have on human life (including to the "ecosystem services" that serve and support human development and sustenance and the other forms of life on Earth[35]).

Critics of economic modeling have expressed concern about the way economists filter the significant complexities of Earth and human systems and the inherent uncertainties in them. Scientists MacCracken and Richardson, for example, point to problems "inherent to the complexity of the Earth system," which they think very difficult if not impossible to capture in the context of an IAM.[36] As they summarize, these include:

1. challenges arising from characteristics of the atmospheric, oceanic, cryospheric, and biospheric components of the climate system, including limits in scientific understanding of how to project the future climate
2. challenges arising from the interactions of [people and institutions] with the climate system[37]

Climate science informs what impacts emissions are likely to have on the natural world, and the potential for damage to human society. But climate science is itself a dynamic process. Climate scientists try continually to improve their understanding through research, observations, and models specific to the disciplines that make up climate science.

To point to one example, a warmer atmosphere and ocean are causing the summer Arctic sea ice to melt. Scientists know this is happening (although the evidence for erosion from a warming ocean has been fairly recent).[38] However, because this is an event outside of previous human experience and direct instrumental measurement, scientists cannot know ahead of time the pace at which future melting will occur, much less the impacts on other natural systems that an ice-free Arctic Ocean might cause. Estimates in 2004 were that the Arctic would be ice free in the summer of 2100; current estimates predict this could happen much earlier, some say as early as this decade.[39] And, it remains to be seen what additional changes to the climate system result from associated radiative forcing—for example, the impacts of increasingly larger areas of dark ocean replacing white sea ice, and how this might affect other parts of the climate system.[40]

Another degree of complexity is found in the difficulty of estimating particular damages that are not usually monetized—for example, the loss of endangered species and of certain kinds of vegetation. The defining image in the popular psyche is the polar bear, but other arctic species such as seals are also endangered. And a number of species more directly connected to natural resources that allow humans to grow food are being disrupted by climate change.[41] The loss of such species is inherent but also connected with other losses that are difficult to quantify.

Another example is the impact of extreme weather—for example, severe flooding in prime agricultural areas that washes out crops and reduces or delays production or shifts it to more climate-tolerant places. There are hundreds of such examples, some of which involve plants and animals, others that involve human lives and communities. Moreover, since humans have always experienced extreme weather events, it is scientifically dubious to attribute any single weather event to a changing climate system. This in itself introduces additional complexities of analysis.

The intellectual puzzle for economists calculating the SCC is how to attach a numeric value to this loss, or to the costs avoided should species survive or even relocate, or should weather cause major changes in the way humans produce food. Even tougher are the methodological challenges associated with monetizing what economists call nonuse environmental benefits. People who may never visit the Himalayas might still be troubled aesthetically or from a geopolitical point of view if glaciers melt. Simply because this is so hard to value, there are benefit categories that get left out in SCC estimates or are valued very conservatively.[42]

None of these are uncertainties about *whether* climate change is happening. Rather, they are uncertainties in calculating the speed of change. Some science projections relating to climate change have been conservative (reflecting the complexity of analysis) and have subsequently been contradicted by experience, such as the swiftly accelerating melt rate for summer Arctic ice.[43]

In truth, human beings have not been very good at predicting either natural or human-made disasters, and therefore have not been prepared for them. The world has recently seen significant examples of miscalculation of risk. In Japan, highly qualified people made calculations of risk of an earthquake, and of a tsunami, but they did not fully understand how the two might work together, and they did not predict a severe enough earthquake or a devastating enough tsunami.

In short, economists who model the SCC must grapple with hugely complex systems and exceptional levels of uncertainty, translating many natural and human variables into monetary values that represent the benefits of acting to control the growth of greenhouse gas emissions. This situation confronts them with a moving target, as climate scientists are continually learning more about how the natural world is responding to the constantly changing array of human influences. The effort through IAMs to impose order on a rapidly evolving set of observations, facts, and data should not obscure the significance of the uncertainties and assumptions inherent in these calculations, and the monetization in these models should be understood within this context as a wide-ranging estimate of costs.

d. Why Is the Discount Rate So Important?[44]

A key variable in calculating the social cost of carbon is the "discount rate." Also known as the "rate of time preference," the discount rate reflects the challenge of capturing the time factor in climate policy.

There are three assumptions built into the discount rate: that humans prefer to receive benefits in the present rather than the future; that future generations will be richer and a dollar is worth less to them as a result; and that there are a variety of investment options for any given sum of money. In addressing climate change, it is an unfortunate truth that the costs of reducing greenhouse gas emissions ("mitigation") must typically begin earlier, while the benefits—in the form of catastrophes or costs avoided—accrue many years, decades, and even centuries in the future. Economic analyses sum the costs current generations might impose on themselves to benefit future generations in the form of a discount rate. The IWG selected discount rates of 2.5 to 5% a year.

The discount rate represents the value of a certain future quantity, translated into today's dollars.[45] Because money earns interest, if one assumes a growing economy with a 6% interest rate—a rate that hasn't been seen in quite a long time—and no inflation, one can expect an investment of $100 to have increased to $106 after one year. Thus a cost of $106 next year is equivalent to $100 today. Other ways of expressing this concept are the present value or the time value of money. It makes a big difference to the SCC, and its policy application, which interest rate or discount rate is used. RFF's Burtraw and Sterner provide a vivid example:

> At a discount rate of one percent, the discounted value of $1 million 300 years [from today] is around $50,000 today. But if the discount rate is five percent, the [current]. . . value is less than a mere 50 cents.[46]

This range of discount rates, which span those commonly used in calculating the SCC, leads to differences in net present value after 300 years that vary by a factor of 100,000.

In the calculation of costs, benefits, and the SCC, the choice of discount rate has enormous impact, influencing whether economists recommend to invest today or much later. From the policy perspective of the economists who value this calculation, the higher the discount rate, the less significant future costs become. The choice of discount rate for investments in managing greenhouse gas emissions, following publication of the Stern Review, ignited intense debates in the economics profession.[47] Stern used a low discount rate, approximately 1.4%. By contrast, William Nordhaus, a professor at Yale University, currently uses a discount rate of about 3% in calculating SCC.[48] Three percent values an environmental cost or benefit occurring 25 years in the future at about half as much as the same benefit today.

The school of thought represented by Nordhaus looks at the evidence that successive generations have been increasingly wealthier and questions why current "poorer" people should in effect reduce their own standard of living and consumption patterns to essentially subsidize future generations. They assume that our progeny will be more able to carry the financial burden (and possibly that future generations will invent technology that we cannot currently imagine).

An underlying assumption is a continually growing economy. The higher discount rate that Nordhaus and his followers advocate shifts more of the burden to future generations, supported by the belief that real rates of return indicate that the world in the future will be better able to make climate investments.

Another approach drawn from this perspective argues that current generations should invest money rather than purchase the technology that would today start the process of reducing greenhouse gas emissions. The return on those investments would then be applied in the future to mitigation activities.[49] The difficulty with this argument is that, as climate change science becomes increasingly concerning, it becomes a weaker bet that future generations will be better off.[50] If they are not, lower or negative discount rates are justified.[51] A high discount rate also requires another risky wager, namely that engineers and technicians will know how to roll back challenging impacts of climate change, such as the thawing of the Greenland ice sheets. Even if future generations are richer, they will be stuck with the physical world we bequeath them.

Applying a low discount rate represents a judgment not to defer these decisions and their related costs to future generations, despite the general assumption that a dollar is worth more today than a dollar tomorrow. Those in favor of a low discount rate point out the unusual nature of climate change. Thus, they focus on the need to set a ceiling now and then to reduce greenhouse gas emissions to avoid atmospheric concentrations rising to levels that might trigger unpredictable and unsolvable catastrophes farther down the road.

But the choice of discount rates involves myriad social and moral judgments, not simple economic calculations. OMB has acknowledged this in guidance on using discount rates, which provides that "it may not be appropriate for society to demonstrate a similar [time] preference when deciding between the well-being of current and future generations."[52] Richard Howarth of Dartmouth College explains why we should care about this somewhat arcane discussion among economists and why it is important to make explicit the consequences of using particular discount rates. As he points out, if countries were to use the discount rates advocated by Nordhaus, "[g]reenhouse gas emission [would] be allowed to grow at a robust rate."[53]

Economists wrestling with these issues admit that many of the elements that either are or ought to be considered to rank the desirability of action against climate change, and at what level, require "normative" judgments; one example is how we weigh the welfare of future generations compared to our own. But many of these value judgments are deeply engrained in the approach neoclassic economics[54] takes to analysis. Decisionmakers outside the profession, and indeed the public, if they entered the debate, might make different assumptions about the present generation's responsibility to future generations and their assumed relative wealth. What may make this conversation particularly confusing to people who don't work with these tools on a daily basis is that the analysis results in a mathematical "answer" comparing benefits and costs, potentially masking the large number of judgments made in the estimation process. It is vital that the SCC be understood with these significant limitations and caveats in mind.

5. What Roles Should SCC and/or Cost-Benefit Analysis Play in Assessing Climate Policy Options?

The discussion above identifies important caveats about various factors employed in IAMs to estimate the SCC. The objections of various climate scientists, expressed in the literature and also in recent workshops conducted by the U.S. Department of Energy and the Environmental Protection Agency, have encouraged some economic modelers to undertake efforts to try to improve the ways their models incorporate climate science.[55] It remains to be seen whether these improvements will produce a more reliable set of numbers to inform OMB review.

In addition, a deeper general critique is surfacing of the very use of these models in the context of assessing and making climate-change policy. Three examples follow.

Economist Frank Ackerman and lawyer Lisa Heinzerling have long questioned the use of cost-benefit analysis to inform environmental policymaking in general.[56] More recently, Ackerman critiqued these tools as applied to climate change, including how the basic tools are used to calculate SCC[57]:

> Cost-benefit analysis assumes that costs and benefits can be expressed in monetary terms with a reasonable degree of confidence . . . The benefits of environmental protection, however, are generally more difficult to quantify. In the case of climate change, economists confront a double problem: the benefits of mitigation are both unpredictable and unpriceable.[58]

University of Chicago Law School professors Jonathan S. Masur and Eric A. Posner, in *Climate Regulation and the Limits of Cost-Benefit Analysis,* approach current practices from another angle, criticizing the methods used to calculate the SCC, and examining the relationship between cost-benefit analysis and politics.[59] They conclude that policy responses to climate change—far from being "data driven" decisions—are inherently political questions "involving contested normative issues."[60] Policymakers, they argue, will have to find alternative tools when those questions predominate.[61] They recommend that cost-benefit analysis be reserved for situations that are politically neutral "in the sense of drawing on widely shared intuitions about human well-being."[62]

Finally, Harvard economics professor Martin Weitzman has systematically called into question the adequacy of cost-benefit analysis, including its component, SCC, as a tool to examine climate-policy alternatives. His initial work focused on the so-called "fat tail."[63] In climate science, the fat tail is the right edge of a distribution of, for example, potential temperature variations caused by climate change. Economists often cut off both extreme sides of the curve (5% on each side) for convenience of analysis. But Weitzman says the fat tail is where they should be looking carefully, because it expresses the probability of extreme events.

> Standard [cost-benefit] analysis trims off the worst-case outcomes with less than a one in twenty chance of happening . . . but Weitzman tells us that seemingly remote possibility is exactly where we should be looking—because the costs are so high they overwhelm other elements of the cost-benefit analysis.[64]

Thus, Weitzman questions whether standard economic models can provide sound advice on the kinds of decisions that policymakers must make about greenhouse gas emissions. In a 2010 paper, Weitzman appeared to question the very use of cost-benefit analysis for evaluating climate-change policy, arguing for a broader public debate on the subject:

> In my opinion, economists need to emphasize more openly to the policy makers, the politicians, and the public that, while formal climate-change [benefit-cost analysis] may be helpful, there is a danger of possible overconfidence from undue reliance on subjective judgments about the probabilities and welfare impacts of extreme events.[65]

Conclusion

U.S. federal agencies are required to conduct a Regulatory Impact Analysis to monetize the anticipated costs and benefits of their proposed actions. In terms of rulemaking related to climate change, the SCC essentially puts a de facto ceiling on the stringency of executive-branch regulation of carbon dioxide. If analyses of specific rules produce SCC figures indicating the rule might impose costs outside the range currently established as acceptable by the federal government interagency working group, namely greater than $65 per tonne of carbon dioxide at the high end, the regulatory agency faces a tough burden of intra-governmental persuasion. In such cases, the choice of SCC can result in weaker control of greenhouse gases, although some advocates for SCC estimates argue that a low positive value is better than zero and can help improve the ambition of a regulation.

The judgments of the IWG—$5, $21, $35, and $65 (in 2007 dollars) per tonne of carbon dioxide—appear on their face to be very concrete. The difficulty with these seemingly rigorous numbers is that they mask a series of choices and value judgments made by the people who run the economic models that produce the final figures.

How these models assess future damages and harms that might occur from climate change is a major issue. Climate scientists research the damage that increasing temperatures and their consequences are imposing on all facets of nature, a uniquely complex undertaking. The economic models essentially selectively filter the climate science, and translate it into numerical representations. An incomplete list of these judgments includes:

- which parts of climate science to factor into the model and at what level of severity
- whether to use a discount rate and what rate to use
- how to account for potentially "catastrophic" climatic events
- how to identify and monetize potential consequences of climate change such as loss of species, mass migrations, spread of disease, and agricultural disruptions and shifts

Perhaps the most important and debated judgment made by modelers is the selection of the discount rate. The IWG selected discount rates of 2.5 to 5% a year. At 3%, a damage that is valued today at $100 in damages shrinks to as little as $5 in a century, suggesting those costs will be less onerous to people in 100 years,[66] and discouraging current regulatory action.

The opacity of the SCC calculation process risks giving policymakers and stakeholders the impression that the numbers are more reliable than they actually are. The assumptions behind the calculation of SCC are not always transparent to policymakers, climate scientists, the public, and sometimes even other economists and economic modelers.

It is a seductive idea that SCC and cost-benefit analysis produce precise numbers backed by hard science. In truth, no single value should be accepted by policymakers unless all the assumptions and choices that underpin the calculation are transparent and well understood. Otherwise the regulatory process risks being held hostage to choices made by unelected experts, rather than grappling with the inherently political and ethical questions posed by climate-change policy.

One way to remedy this problem is through more robust dialogue between economists developing the SCC and climate scientists and others working to understand the damages that climate change is imposing. Climate and social scientists should have a direct role in the SCC calculation process.[67]

Notes

1. Converted from U.K. pounds to U.S. dollars in 2000.
2. William D. Nordhaus, A Question of Balance: Weighing the Options on Global Warming Policies (2008).
3. Exec. Order No. 12,291, 3 C.F.R. 127 (1982); Exec. Order No. 12,866, 3 C.F.R. 638 (1994).
4. Dominic J. Mancini, Office of Inform. & Regulatory Affairs, U.S. Office of Mgmt & Budget, The Am. Experience in Regulatory Review and Reform (2006), *available at http://ec.europa.eu/agriculture/events/simplification/mancini.pdf* ("During our review, we examine the RIA and the regulation and make suggestions to improve both the RIA and the rule's cost-effectiveness and to make sure that it comports with the Executive Order's principles and the President's priorities. If the agency refuses to make changes or needs more time to make the changes, we can return the rule to the agency for reconsideration.") James F. Morrall, III, a retired career official at OMB, describes the process and calls the head of the OIRA, the regulatory arm of OMB, the "regulatory Czar." John F. Morrall, III, U.S. Experience with Regulatory Oversight History and Use of RIA (2010), *available at http://www.gwu.edu/~clai/recent_events/2010/Spring_Regulatory_Program/Speaker%20Presentations/US_Experience_with_Regulatory_Oversight_2010.pdf*.
5. The benefits can be estimated by multiplying the change in GHG emissions in a year by the SCC value appropriate for that year. The net present value (in other words, the value in today's dollars) of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years.
6. For example, the National Highway Traffic Safety Administration (NHTSA) used an SCC value ranging on the low end from $2 (a domestic value) to $80 (a global value) in its March 2009 final rule for vehicle fuel economy. Final Rule, Average Fuel Economy Standards, Passenger Cars and Light Trucks, 74 Fed. Reg. 14,196, 14,346 (Mar. 30, 2009). In 2008, NHTSA used an SCC value of $7 in its proposed fuel economy standard. Notice of Proposed Rulemaking, Average Fuel Economy Standards, Passenger Cars and Light Trucks; Model Years 2011–2015, 73 Fed. Reg. 24,352, 24,414 (May 2, 2008).
7. Commercial Standard Sized Packed Terminal Air Conditioners and Packed Terminal Heat Pumps, 73 Fed. Reg. 58,772 (Oct. 7, 2008).
8. The interagency working group states its objective as "making it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or 'marginal,' impacts on cumulative global emissions. Most federal regulatory actions can be expected to have marginal impacts on global emissions." U.S. Dept of Energy, Final Rule Technical Support Document: Energy Efficiency Program for Commercial and Indus. Equipment: Small Electric Motors, Appendix 15A. Social Cost of Carbon for Regulatory Impact Analysis under Exec. Order 12866 13 (Mar. 9, 2010) [hereinafter IWG Report], *available at* http://www1.eere.energy.gov/buildings/appliance_standards/commercial/sem_finalrule_tsd.html.
9. Council of Economic Advisors, Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, and Office of Science and Technology Policy.
10. There was no specific guidance on which value to use in specific rulemakings. This lack of guidance is understandable, given that the differences are mostly related to using a variety of discount rates.
11. Final Rule, Average Fuel Economy Standards, Passenger Cars and Light Trucks, *supra* n. 6; Corporate Average Fuel Economy Standards, 75 Fed. Reg. 25,324, 25,520 (May 7, 2010); Energy Conservation Program: Energy Conservation Standards for Small Electric Motors, 75 Fed. Reg. 10,874, 10,909 (Mar. 9, 2010); Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters, 75 Fed. Reg. 20,112, 20,177 (Apr. 16, 2010).
12. IWG Report, *supra* n. 8, at 40.
13. *Id.* at 34.
14. Climate Change Economics, Dept. of Energy and Climate Change, *Carbon Valuation in UK Policy Appraisal: A Revised Approach* (July 2009), *available at http://www.decc.gov.uk/assets/decc/what%20we%20do/a%20low%20carbon%20uk/carbon%20valuation/1_20090715105804_e_@@_carbonvaluationinukpolicyappraisal.pdf*

15. Frank Ackerman & Elizabeth A. Stanton, The Social Cost of Carbon 17 (2010), *available at http://sei-international.org/mediamanager/documents/Publications/Climate-mitigation-adaptation/socialcostofcarbon_sei_20100401.pdf* (citing figures used in Climate Change Economics, *supra* n. 14, at 119). In 2002, the U.K. Government Economic Service (GES) recommended an illustrative estimate for the SCC of £70/tonne of carbon (tC), within a range of £35 to £140/tC (for year 2000 emissions), for use in policy appraisal across government, and that these values should be increased at the rate of £1/tC per year. R. Clarkson and K. Deyes, *Estimating the Social Cost of Carbon Emissions* 41 (Govt. Econ. Serv. Working Paper 140, Jan. 2002), *available at* http://www.hm-treasury.gov.uk/d/SCC.pdf. The GES also recommended that these values should be subject to periodic review. *Id.* at 42.

16. Ackerman & Stanton, *supra* n. 15, at 1.

17. IWG Report, *supra* n. 8, at 2.

18. Ackerman & Stanton, *supra* n. 15, at 4.

19. This discussion relies heavily on Ackerman & Stanton, *supra* n.15.

20. Because of seasonal differences, the figure is every four years in Hawaii or every six weeks in Maine.

21. Some have pointed out that that this ignores some of the non-climate related co-benefits of reducing CO_2, including immediate health benefits. More research is showing those estimates of benefits to be very high. For example, scientists have found that introducing low-emissions cookstoves in India would significantly reduce premature deaths caused by acute lower respiratory infections, ischemic heart disease, and chronic obstructive pulmonary disease. Paul Wilkinson et al., *Public Health Benefits of Strategies to Reduce Greenhouse-Gas Emissions: Household Energy*, 374 Lancet 1917–29 (2009).

22. Frank Ackerman & Charles Munitz, Climate Damages in the FUND Model: A Disaggregated Analysis (2011), *available at http://www.e3network.org/papers/Climate_Damages_in_FUND_Model_March2011.pdf*.

23. The Dynamic Integrated Climate Change (DICE) model was developed at Yale University by William Nordhaus, David Popp, Zili Yang, Joseph Boyer, and colleagues.

24. The Policy Analysis of Greenhouse Effect (PAGE) model was designed by Dr. Chris Hope, Reader in Policy Modelling at University of Cambridge Judge Business School.

25. The *Climate Framework for Uncertainty, Negotiation and Distribution (FUND) was developed by Richard Tol and David Anthoff.*

26. This section relies heavily on Michael D. Mastrandrea, Representation of Climate Impacts in Integrated Assessment Models, Workshop Proceedings (2010), *available at http://www.pewclimate.org/docUploads/mastrandrea-integrated-assessment-models.pdf*.

27. Monte Carlo analysis is a form of probabilistic testing using computerized mathematical formulas to do repeated random sampling. Doing this allows the modeler to consider a range of possible outcomes and the probabilities they will occur for any choice of action, including extreme possibilities from the most radical to the most conservative decision. This is a technique that was devised by scientists working on the atom bomb, named for the Monaco casino resort mecca.

28. Douglas Fischer & Nicole Heller, *Revised Figures Show Federal Economists Understate the Costs of Climate Impacts*, Climate Central (Jan. 26, 2011), http://www.climatecentral.org/news/revised-figures-show-federal-economists-understate-the-cost-of-climate/.

29. For example, although most economists assume that wealth will continue to increase, as it has historically, changing weather might lower economic growth and human well-being; future generations could be considerably poorer than current ones (see discussion below concerning discount rate at Section 4.d). Also, extreme weather changes may trigger human migrations from less habitable to more habitable parts of the Earth, a trend that could provoke social conflict.

30. Elizabeth A. Stanton, Frank Ackerman, & Sivan Kartha, *Inside the Integrated Assessment Models: Four Issues in Climate Economics*, 1 Climate and Dev. 166–84 (2009).

31. A 95% confidence interval means that in the statistical model, the "true" value has a 95% chance of being within the interval.

32. *Ackerman* & Munitz, *supra* n. 22.

33. Frank Ackerman et al., *Limitations of Integrated Assessment Models of Climate Change*, 95 Climatic Change 297–315 (2009).

34. Paul Slovic, *Perception of Risk,* 236 Science 280–85 (1987).

35. Ecosystems are the systems in the natural world that provide benefits ("services") to human beings. Services can include clean water or the insects that pollinate to allow food to be grown. Rudolf S. de Groot, Matthew A. Wilson, & Roelof M.J. Boumans, *A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services,* 41 Ecological Econ. 393–408 (2002).

36. Michael C. MacCracken & L. Jeremy Richardson, Challenges to Providing Quantitative Estimates of the Environmental and Societal Impacts of Global Climate Change (2010), *available at http://www.pewclimate.org/docUploads/maccracken-richardson-challenges-quantitative-estimates.pdf*.

37. *Id.*

38. T.B. Salles, C.M. Griffiths, C.P. Dyt & F. Li, *Australian Shelf Sediment Transport Responses to Climate Change-Driven Ocean Perturbations,* 282 Marine Geology 268–74 (2011); E. Rignot et al., *Acceleration of the Contribution of the Greenland and Antarctic Ice Sheets to Sea Level Rise,* 38 Geophysical Research Letters L05503 (2011).

39. *Ice-Free Arctic Summers Likely Sooner Than Expected*, National Oceanic and Atmospheric Association (Apr. 2, 2009), *http://www.noaanews.noaa.gov/stories2009/20090402_seaice.html*. For the earlier prediction, see, e.g., Richard Black, *New Warning on Arctic Sea Ice Melt*, BBC News (Apr. 7, 2011), *http://www.bbc.co.uk/news/science-environment-13002706*; David Ljunggren, *Arctic Summer Ice Could Vanish by 2013: Expert*, Reuters (Mar. 5, 2009), *http://www.reuters.com/article/idUSTRE52468B20090305*; *February Arctic Ice Extent Ties 2005 for Record Low; Extensive Snow Cover Persists*, National Snow and Ice Data Center (Mar. 2, 2011), *http://nsidc.org/arcticseaicenews/2011/030211.html*.

40. J.E. Overland et al., National Oceanic and Atmospheric Association, Arctic Report Card: Update for 2010: Atmosphere (2011), *available at* http://www.arctic.noaa.gov/reportcard/atmosphere.html.

41. *See, e.g.,* Food and Agriculture Organization of the United Nations, Rome, Italy, Feb. 13–14, 2008, *Climate Change and Biodiversity for Food and Agriculture* 2–3 (2008) ("climate change may lead to loss of functional biodiversity and to localized impacts in the delivery of ecosystem services such as lack of pollination, loss of soil biodiversity and capacity for nutrient cycling, or loss of natural biological control leading to potential new pest outbreaks"), *available at ftp://ftp.fao.org/docrep/fao/meeting/013/ai784e.pdf*; Global Climate Change Impacts in the United States 71–78 (Thomas R. Karl, Jerry M. Melillo, & Thomas C. Peterson eds., 2009), *available at http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts*.

42. The methodology economists use to perform this function is called willingness to pay assessments or contingent valuation methodologies. For a critique of such methods, see John Broome, *Valuing Policies in Response to Climate Change: Some Ethical Issues*, *available at http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/stern_review_supporting_documents.htm*.

43. *See supra* n. 39.

44. This section depends very heavily on Chris Hope & David Newbery, *Calculating the Social Cost of Carbon* (May 3, 2006), *available at http://www.eprg.group.cam.ac.uk/wp-content/uploads/2008/11/eprg0720.pdf*, and Stephen Newbold et al., *The "Social Cost of Carbon" Made Simple* (U.S. EPA National Center for Environmental Economics, Working Paper No. 10-07, 2010).

45. Dallas Burtraw & Thomas Sterner, *Climate Change Abatement: Not 'Stern' Enough?,* Resources for the Future (Apr. 4, 2009), *http://www.rff.org/Publications/WPC/Pages/09_04_06_Climate_Change_Abatement.aspx*.

46. *Id.*

47. The debate and the consequences of the discounting rate are illustrated by economist Hal R. Varian in *Recalculating the Costs of Global Climate Change*, N.Y. Times, Dec. 14, 2006, *available at http://www.nytimes.com/2006/12/14/business/14scene.html*.

48. In 1994, Nordhaus advocated for a discount rate of about 6%. William D. Nordhaus, Managing the Global Commons: The Economics of Climate Change (1994).

49. Howarth makes the point that there is not only one rate of return on capital. Richard B. Howarth, *Discounting and Uncertainty in Climate Change Policy Analysis*, 79 Land Economics 369–81 (2003).

50. Richard B. Howarth, *Discounting, Uncertainty, and Revealed Time Preference,* 85 Land Economics 24–40 (2009).

51. Partha Dasgupta, *Discounting Climate Change,* 37 J. Risk and Uncertainty 141–69 (2008).

52. Office of Mgmt and Budget, Circular A-4 (2003), *available at http://www.whitehouse.gov/omb/circulars_a004_a-4/#e*.

53. Howarth, *supra* n. 50, at 1.

54. Loosely, neoclassical economics rests on three assumptions: people have rational preferences among outcomes that can be identified and associated with a value; individuals maximize utility and firms maximize profits; and people act independently on the basis of full and relevant information. E. Roy Weintraub, *Neoclassical Economics* in The Concise Encyclopedia of Economics, *available at* http://www.econlib.org/library/Enc1/NeoclassicalEconomics.html.

55. U.S. EPA, Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis: Modeling Climate Change Impacts and Associated Economic Damages, *available at http://yosemite.epa.gov/ee/epa/eerm.nsf/vwRepNumLookup/EE-0564?OpenDocument*.

56. Frank Ackerman & Lisa Heinzerling, Priceless: On Knowing the Price of Everything and the Value of Nothing (2005).

57. Ackerman et al., The Need for a Fresh Approach to Climate Change Economics (2010), *available at http://www.pewclimate.org/docUploads/ackerman-decanio-howarth-sheeran-climate-change-economics.pdf*.

58. Social cost of carbon does not calculate the "costs" side of the cost-benefit equation. Ackerman's critique of the larger issues of cost-benefit expresses the difficulty of monetizing essentialities such as clean water and air. A longer discussion of this is found in Ackerman & Heinzerling, Priceless, *supra* n. 56.

59. Jonathan S. Masur & Eric A. Posner, *Climate Regulation and the Limits of Cost-Benefit Analysis* (John M. Olin Law & Econ., Working Paper No. 525, Pub. Law and Legal Theory, Working Paper No. 315, 17 (August 2010), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1662147##.

60. *Id.* at 6.

61. *Id.* at 34.

62. *Id.* at 6.

63. Martin L. Weitzman, *On Modeling and Interpreting the Economics of Catastrophic Climate Change*, The Review of Economics and Statistics (Feb. 2009).

64. M. Kimble & L. Tawney, *The Tail of the Fat Tail*, 26 Environmental Forum 24 (May/June 2009), *available at http://www.globalproblems-globalsolutions-files.org/unf_website/PDF/articles/UNF_EC_TaleFatTail_KimbleTawney_0907.pdf*.

65. M. Weitzman, *Revising Fat-Tailed Uncertainties in the Economics of Climate Change* (Aug. 23, 2010), *available at http://www.economics.harvard.edu/faculty/weitzman/files/REEP%2Bfinal%2Bfat.pdf*.

66. Ackerman & Stanton, *supra* n.15.

67. Two workshops on SCC sponsored by the U.S. DOE and EPA in November 2010 and February 2011 represent a welcome step forward in fostering such dialogue.

About the World Resources Institute

The World Resources Institute is a global environmental think tank that goes beyond research to put ideas into action. We work with governments, companies, and civil society to build solutions to urgent environmental challenges. WRI's transformative ideas protect the earth and promote development because sustainability is essential to meeting human needs and fulfilling human aspirations in the future.

WRI spurs progress by providing practical strategies for change and effective tools to implement them. We measure our success in the form of new policies, products, and practices that shift the ways governments work, companies operate, and people act.

We operate globally because today's problems know no boundaries. We are avid communicators because people everywhere are inspired by ideas, empowered by knowledge, and moved to change by greater understanding. We provide innovative paths to a sustainable planet through work that is accurate, fair, and independent.

Each World Resources Institute brief represents a timely, scholarly treatment of a subject of public concern. WRI takes responsibility for choosing the study topics and guaranteeing its authors and researchers freedom of inquiry. It also solicits and responds to the guidance of advisory panels and expert reviewers. Unless otherwise stated, however, all the interpretation and findings set forth in WRI publications are those of the authors.

About the Environmental Law Institute

The Environmental Law Institute makes law work for people, places, and the planet. The Institute has played a pivotal role in shaping the fields of environmental law, policy, and management, domestically and abroad. Today, ELI is an internationally recognized independent research and education center known for solving problems and designing fair, creative, and sustainable approaches to implementation.

ELI strengthens environmental protection by improving law and governance worldwide. ELI delivers timely, insightful, impartial analysis to opinion makers, including government officials, environmental and business leaders, academics, members of the environmental bar, and journalists. ELI is a clearinghouse and a town hall, providing common ground for debate on important environmental issues.

The Institute is governed by a board of directors who represent a balanced mix of leaders within the environmental profession. Support for the Institute comes from individuals, foundations, government, corporations, law firms, and other sources.

ELI publishes books, research reports, and several periodicals to educate the profession and to stimulate a robust and creative exchange of ideas. ELI Press publishes books by a wide array of authors, whose opinions are not necessarily those of the Institute, its Board of Directors, or funding organizations. ELI welcomes suggestions for book topics and encourages the submission of draft manuscripts and book proposals.

The authors gratefully acknowledge the tutoring, review and editing thoughts of the following people; any mistakes we made after such amazing help were our own: Scott Schang, Kristen Sheeran, James Barrett, Laurie Johnson, Bud Ward, Jake Blumgart, Jeremy Richardson, Kevin Kennedy, Karl Hausker, Frances Irwin, Janet Ranganathan (especially for a great title), Letha Tawney, Micah Ziegler, James Bradbury, Edward Cameron, Mercedes Stickler and one anonymous reviewer, and the patient help of Hyacinth Billings, Rachel Jean-Baptiste, and Maggie Powell in preparing the final document.