THE VALUE OF STATISTICAL LIFE AND THE SOCIAL COST OF CARBON

by

Ethan Case

Dr. Timothy Johnson, Adviser

April 2013

Masters project submitted in partial fulfillment of the

requirements for the Master of Environmental Management degree in

the Nicholas School of the Environment of

Duke University

2013

Abstract

In light of the consistent inability of the legislative branch to craft and pass legislation that effectively addresses global warming and a series of court cases that compel action on climate change from the executive branch, it appears likely that short and medium-term efforts to address the problem must come in the form of executive branch actions. These executive actions must be justified by cost-benefit analyses. The current metric used to value the benefits of greenhouse gas reduction policies is the Social Cost of Carbon estimate, a number intended to price the damage done to the economy by each ton of CO^2.

This paper examines the intersection of the Social Cost of Carbon (SCC) estimate and the Value of Statistical Life (VSL) estimate currently used by federal agencies to value mortality risk reductions in policymaking. Two of the three climate damage models underlying the SCC estimate currently use comparable mathematical approaches to model VSL equivalents. The mathematical approaches for modeling VSL estimates in climate damage models have been isolated to reveal how various national VSL values would likely appear if the SCC estimate was subject to a more thorough analysis. Modeled VSL results also then compared with observed VSL results from the literature.

While the magnitude of the effect of changes in the VSL remains small except in cases of catastrophic events, the application of modeled VSL estimates in climate damage models used to formulate global climate policy raises new and compelling ethical quandaries. The economic and corresponding ethical assumptions of the application of modeled VSL estimates in climate damage models are discussed within. Particular attention is paid to the effects of the Kaldor-Hicks efficiency criterion, VSL estimates and income inequality, and VSL estimates and catastrophic damages. Alternative points of view such as rights-based policy making and environmental justice insights are briefly taken into account. Finally, international policy implications are discussed and recommendations for the improvement of the SCC process in light of this analysis are advanced.

Statement of Purpose & Introduction

How we choose to value global warming impacts now will likely have a profound effect upon the state of the atmosphere and human well-being in the future. Currently, the prevailing policy approach of the United States and other developing countries is to frame valuation of global warming impacts as an economic issue. Because many projected impacts of global warming fall out of the conventional purview of economists, many impacts, such as effects upon ecosystem and human well-being, are very hard to value in economic terms. Valuing hard-to-value non-market impacts of climate change requires choices, and choice requires an ethical framework. The purpose of this paper is to explore the underlying ethical assumptions about how we choose to value the impacts of global warming in relation to the worst risk of all: the loss of human life.

To achieve this end, this paper examines two prevailing economic concepts used to place value on global warming impacts, the Social Cost of Carbon, and to value the reduction of mortality risk, the Value of Statistical Life. The intersection of these two concepts in climate damage models is examined and many underlying ethical considerations currently underemphasized in the climate policy discourse are brought to light.

This paper begins with an introduction to the processes of the Interagency Working Group Social Cost of Carbon including why it was convened, the economic methods employed in deriving the social cost of carbon estimate, how economic assumptions with ethical implications were handed by the Working Group, and how specifically the estimate is used to guide policymaking. The paper then examines the how Value of Statistical Life estimates affect Social Cost of Carbon estimate and ethical considerations that arise when applying VSL estimates to domestic climate policy. Then, a comparative analysis of observed VSL estimates and VSL as modeled by DICE and FUND is undertaken to see how well observations match models. Following this analysis the Value of Statistical Life in climate damage models is then considered in light of the possibility of catastrophic risks. Finally, international policy considerations of the potential effects of VSL in climate policy are examined.

Background on the Social Cost of Carbon

Until climate legislation is enacted in the US, the ability to address climate change rests with the federal government's authority granted by Congress in existing statutes. In the landmark Supreme Court case *Massachusetts v. EPA* (2007), the state of Massachusetts and others petitioned the EPA to begin to act upon climate change[i] based upon statues in the Clean Air Act. The majority ruled that the EPA must issue an Endangerment Finding to determine "whether greenhouse gas emissions contribute to climate change."[ii] When the EPA determined that greenhouse gases do contribute to climate change and issued an

Endangerment finding, the agency was legally required to begin developing greenhouse gas regulations in accordance with Clean Air Act statutes.

Parallel to developments in *Massachusetts v. EPA* was a federal case involving the National Highway Transportation Traffic Safety Administration (NHTSA) in the Ninth Circuit Court in 2007.[iii] The NHSTA argued that the value for Co^2 reeducations should be excluded in the policy cost-benefit analysis due to the wide range of values for CO^2 reduction benefits in economic literature. The court ruled that the "NHSTA's reasoning is arbitrary and capricious for several reasons…first, while the record shows that there is a range of values, the value of carbon emissions reduction is certainly not zero."[iv]

The Ninth Court's ruling on the NHSTA cost benefit analysis and the EPA's legal obligation to act under the Clean Air Act after the endangerment finding created the need for a more robust estimate of CO^2 damages for regulations.[v] It became apparent that in order to develop and implement regulations aimed at reducing greenhouse gas emissions, it was necessary to comply with Executive Order 12866, which requires a cost-benefit analysis of their proposed action for all policies that cost more than $100 million.[vi] To calculate the costs and benefits of greenhouse gas emissions, it was necessary to come up with a point estimate of the cost of a unit of CO^2 emitted. This was no simple task: it required a comprehensive look at the economic damages and benefits associated with climate change.

The Obama Administration tackled this challenge by convening an Interagency Working Group on the Social Cost of Carbon (SCC) with participants from relevant government agencies and advisory committees. The working group analyzed the results from 3 climate damage models to come up with a range of carbon damage estimates published in February of 2010. The primarily deliverable of the working group was the Social Cost of Carbon: a range of point estimates of the cost of damage each ton of carbon dioxide caused to the planet's economy at a given time. The results are shown in figure 1. The 3% average indicates the central estimate that is used in agency cost-benefit analysis.

Various discount rates are applied in Figure 1 due to the wide range of impacts upon the outcome caused by the rate assumed to be correct. The Interagency Working Group advises that the 3% is the appropriate discount rate be applied in normal regulatory analysis. The 5% discount rate is meant to show policy makers what the value would be if it were higher. The 2.5% discount rate is included to a reflect an ongoing debate about an alternative way to apply discount rates using the Ramsey pure-rate of social time preference. Essentially, this discounting method for policy-makers hedged for the fact that future generations may choose a different discount rate for the valuation of carbon in the future than the decision-makers choose for the future generation now. The 95^{th} percentile column indicates SCC estimates in a situation where damages fall within the highest 5 percent of projected damages. This is meant to take into account a future would in which the economic damages of climate change are in fact much worse than the models calculate. The numbers in all columns grow over time based upon the assumption that the damage done by each ton of CO^2 rises linearly as more carbon is added to the atmosphere.[vii]

The estimate was first applied as part of the cost benefit analyses by the EPA to its Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards in 2010.[viii] Later, it was applied by the Department of Energy as part of the Energy Conservation Standards for Small Electric Motors and Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters.[ix] The SCC will also be applied in regulatory analysis and proposed rule-making. Importantly, the proposed EPA rule for carbon regulation standards for new power plants may also include the SCC estimate if it is finalized.[x]

Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

Figure 1: Social Cost of Carbon Estimates

After the prospect of climate legislation became bleak in 2010, the SCC estimate grew in importance. In Obama's 2013 State of the Union Address, the president was unequivocal about making climate action a priority, stating that "if Congress won't act soon to protect future generations, I will."[xi] Any unilateral presidential action would have to be taken through the Executive branch, which would require cost benefit analyses for regulations. To undertake these analyses, federal agency actions will likely use the SCC estimate, thus, making the estimate a very important policy tool in the coming years. Perhaps unintentionally, the SSC may quickly become a keystone of American climate policy.

Using Climate Damage Models to Inform Climate Policy Decisions

Evaluating damages caused by climate change has a rationale that extends beyond satisfying the requirements of an executive order. Determining the cost of an additional ton of CO^2 is the current method by which we determine the economically optimal level of CO^2 pollution.[xii] At a basic level this can be viewed as determining where the cost of reducing CO^2 emissions equals the avoided economic damage that the gases would have done to the economy had they been released. This is represented graphically in Figure 1[xiii] below. Too much abatement (to the right of equilibrium) leads to over protection from global warming, and would mean spending too many resources on climate change adaptation and mitigation, thereby decreasing social welfare by diverting limited resources from other activities that would otherwise improve social welfare. Under protection (to the left of equilibrium) means incurring costs caused by climate change that should be avoided with additional investment in mitigation and adaptation if people chose the optimal least cost path.

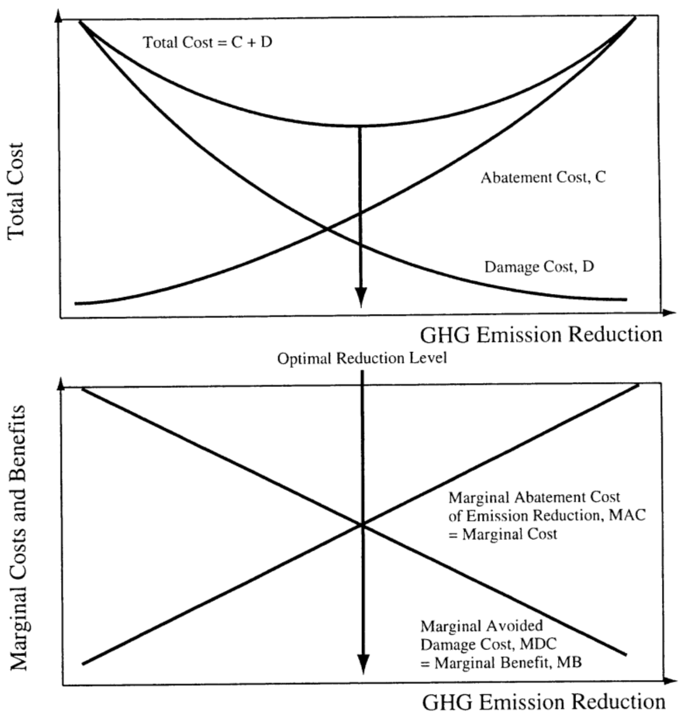

Figure 2: Marginal CO2 Reduction Costs

This simplistic approach presented in Figure 1[xiv] is confounded by many unique problems caused by climate change, including a complex chain of causality between impacts and economic damages, the probable irreversibility of climate change, the global nature of the problem, the uncertain geographic and temporal distribution of costs and benefits, the nonlinearity of damage distributions, and the very long time frame of the problem.[xv] To address these and other challenges of valuing the costs and benefits of climate change and emissions reductions policies, economic experts have developed a few dozen complex economic models to determine the economically optimal level at which to reduce greenhouse gases. These models represent the best, imperfect attempt to overcome uncertainties and unknowns while providing estimates regarding costs and damages to help guide policy-making.

A major part of the work of the federal government's Interagency Working Group on the Social Cost of Carbon was to pick through the many climate damage models and decide which models would be used to estimate the Social Cost of Carbon for America. The working group chose three integrated assessment models on the basis that they frequently cited in peer-reviewed economic literature and that they were used in the 4th IPCC assessment report.[xvi] These models were DICE, the Dynamic Integrated Climate and Economy model first developed by William Nordhaus in 1990, the Policy and Analysis of the Greenhouse Gas Effect model developed by Chris Hope beginning in 1991, and FUND, the Climate Framework for Uncertainty, Negotiation, and Distribution developed by Richard Tol in the early 1990s.[xvii]

These and other integrated assessment models attempt to model the global economy, the climate system, and the interaction between the changing climate system and the global economy. Basically, this involves translating changes in atmospheric greenhouse gas concentrations into temperature changes and then temperature changes into economic damages in terms of global and regional GDP.[xviii] The models differ significantly in their initial assumptions, required data input, mathematical approaches applied to translate temperature changes into economic damages. A key similarity of the three models is that they are reduced-form, or, relatively simple compared to the myriad of other climate damage models available and hence relatively easier for large groups of people to comprehend.[xix]

To derive the marginal cost of an additional ton of CO^2, or the Social Cost of Carbon, is relatively simple once the models are run. DICE, for instance, calculates the total economic output in the form of utility and the total emissions for a year's time. To calculate the marginal cost of CO^2 and the social cost of carbon in DICE, modelers must simply find the effect of one additional ton of CO^2 upon total utility. This is done by subtracting the total utility with one additional ton of CO^2 emissions from base case total utility calculated by the model. Analogous methods were applied to FUND and PAGE, the results were averaged, and then various discount rates were applied to determine the net present value of benefits.

Uncertainty is part and parcel of climate damage modeling and leads to inherent limitations in results. The authors of the Social Cost of Carbon report themselves explicitly point this out by concisely summarizing a 2009 NRC study. They state that the social cost of carbon experiences uncertainty caused by a lack of knowledge about:

> "(1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages."[xx]

Such uncertainty and the modeling limitations they present have led to significant caveats being added to the Social Cost of Carbon analysis. These caveats include:

- Incomplete treatment of non-catastrophic damages
- Extrapolation of climate damages to high levels of warming
- Incomplete treatment of adaptation and technological change:
- Risk aversion[xxi]

The significance of these caveats and their relationship to approaching Value of Statistical Life (VSL) estimates estimated by the models, particularly the treatment of catastrophic risk and VSL estimates, will be addressed later on.

Deferring Assumptions to Modelers in the Social Cost of Carbon Analysis Process

The authors of the SSC defer to the expert modelers stating that "underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships."[xxii] Some of the key differing assumptions in integrated assessment models have been explored by Richard Tol and Samuel Frankenhauer. They identify three basic assumptions of most integrated assessment models describing climate damages: that the impact categories considered are sufficiently comprehensive, that the level of spatial detail is appropriate, and that the measurement of the impact is accurate.[xxiii]

Because these three basic assumptions vary across models, isolating and comparing the effects of various modeling assumptions upon particular vectors such as accurate representation of Value of Statistical Life estimates or ecosystem services contributions to global utility is exceedingly difficult. For instance, one model may apply a value to lost crops due to global warming in one aggregated region of the world representing the US, another model may examine North America, and a third may simply aggregate values for the entire world by examining global markets with no regional calculations. This means isolation of very important policy-relevant intermediate vectors such as lives lost, acres of ecosystems destroyed, or land lost due to sea-level rise is difficult to critically examine and update in light of the latest research. It also makes it exceedingly difficult for modelers to improve particular mathematical approaches based upon better model parameters. Finally, it puts a huge analytical burden on time-strapped modelers to attempt to keep track of all climate-related research for each of their parameters, a task very difficult for any one human to achieve.

Deferring to the creators the integrated assessment models, DICE, PAGE, and FUND, streamlined a very difficult discussion and allowed the Interagency Working Group to come to a consensus in a reasonable period of time to make initial policy recommendations. The report states that the primary reason for deferring to modelers was that "given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program."[xxiv] However, this deference took a discussion of assumptions and approaches in integrated assessment models off of the table. Removing underlying model assumptions from the table also removes discussions about the ethical issues that have been a fundamental part the Social Cost of Carbon discussions in other developed countries. According to Ruth Greenspan of the *World Resources Institute*,

> "The [Social Cost of Carbon] exercise involves many judgment calls that are largely hidden in complex economic models and that may be invisible to policymakers and stakeholders. When these judgments are embedded in economic models, policymakers and stakeholders do not have the opportunity to discuss and directly debate the underlying complex value choices. In some instances, decision-makers may not realize that choice of models and factors contain essentially ethical and other considerations. In addition, the process of making calculations often omits essential information, such as the possibility of a very severe outcome." [xxv]

One ethically laden area not discussed by the Interagency Social Cost of Carbon Working Group that could propagate significant errors in both valuation and ethical judgment is the valuation of non-market goods. Non-market goods include ecosystems services and the valuation of project loss of life due to climate change. Valuation of non-market factors are almost exclusively derived from contingency valuation, a catchall term for survey methods used to monetize non-market goods. The market price of a non-market good is then used in cost-benefit analyses as a "contingent value" to stand in for the non-market good as costs and benefits are tallied.[xxvi]

There is strong evidence to suggest that contingency values for non-market goods are heavily influenced by the ethical framework of the respondents.[xxvii] However, in the case of the Social Cost of Carbon process, many of these ethical frameworks that affect non-market values are decided by a modeler based upon research and have not been reviewed by independent observers for consistency. It is probable that most of the models do not take into account the fact that ethical frameworks have impacts upon the valuation of market goods. In the case of DICE 2007, for instance, the health data used in projecting estimated loss of life was published in 1996 with no mention of the ethical frameworks.[xxviii] While it makes sense to exclude such ethical considerations from a purely academic model, once it is applied to policy analysis such issues ought to be considered.

Economist Michael Hanemann of UC Berkley and Arizona State University argues that the hardest task in the social cost of carbon process is creating a method to calculate and value non-market impacts of climate change. [xxix] He points out that in many cases integrated assessment models such as DICE 2002 (DICE 2007 was used in the SCC process), non-market damages exceed market damages. [xxx] In many scenarios of catastrophic damages in DICE 2002, non-market damages exceed market damages by 10-fold.

Thus the largest part of the damages in the models used in the SCC process can be significantly affected by ethical assumptions that have as yet remained unexamined by the federal government.

This situation has likely led to significant error propagation in the SCC process that could have been avoided. As Tol and Frankenhauser point out:

> "IAMs reflect at best the state of the art of the underlying literature. The models using aggregate impact measures often just mimic one particular published estimate…thus mimicking its shortcomings and differences with other studies. Variations in the set of impacts covered may also reflect a difference in opinion about the scientific reliability of some impact estimates, either between IA modelers themselves, or as passed on from the underlying literature."[xxxi]

In the Social Cost of Carbon Analysis, the SCC values of three IAMs were averaged. According to Tol and Frankenhauser, any error in one means a likelihood of errors in another. Hanemann argues also that such averaging understates the overall climate damages.[xxxii] Another byproduct of averaging is a highly inconsistent ethical framework for approaching climate policy.

Relevance of VSL Assumptions to Climate Damage Models

One of the major ethically-laden assumptions deferred to modelers in the SSC is the calculation of the Value of Statistical Life. The Value of Statistical Life (VSL) is not the actual monetary value of statistical life.[xxxiii] "Rather, when conducting a benefit-cost analysis of new environmental policies, the Agency [the EPA] uses estimates of how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by environmental pollution."[xxxiv] The EPA's explanation through an example is a simple illustration of the concept.

> "Suppose each person in a sample of 100,000 people were asked how much he or she would be willing to pay for a reduction in their individual risk of dying of 1 in 100,000, or 0.001%, over the next year. Since this reduction in risk would mean that we would expect one fewer death among the sample of 100,000 people over the next year on average, this is sometimes described as "one statistical life saved." Now suppose that the average response to this hypothetical question was $100. Then the total dollar amount that the group would be willing to pay to save one statistical life in a year would be $100 per person × 100,000 people, or $10 million."[xxxv]

To derive the Value of Statistical Life estimate, the EPA uses stated preference and hedonic wage studies and stated preference surveys. Hedonic wage studies and stated preference studies attempt to derive a market price for an activity that has no market. Hedonic wage studies entail a surveyor asking a worker how much she would be willing to give up to avoid a particular risk. [xxxvi] Stated preference studies ask respondents hypothetical questions about how much money they would spend in a given situation to determine preferences and values.[xxxvii] The EPA has a long list of criteria to determine which specific hedonic wage analysis and stated preferences to use when determining the official Value of Statistical Life estimate.[xxxviii] The current estimate used by the EPA is $7.4 million.[xxxix]

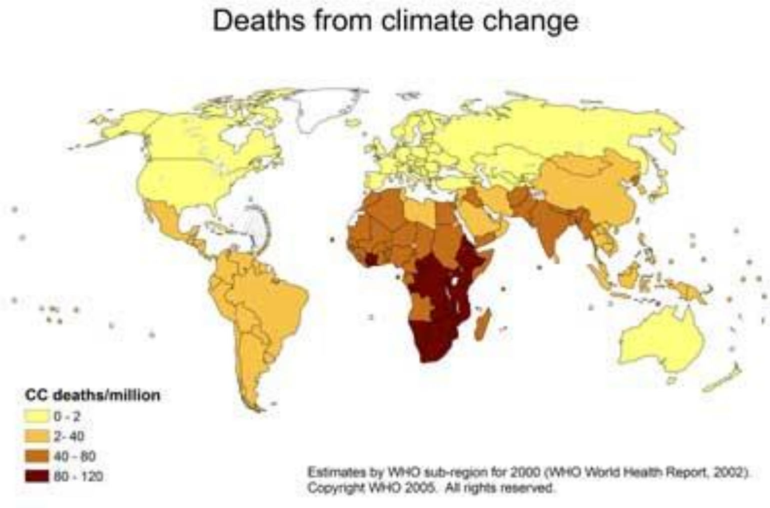

Figure 3: World Health Estimates of Climate-Induced Death (World Health Organization)

Importance of VSL in Climate Damage Modeling

Death influenced or caused by climactic factors is immensely difficult to directly attribute to climate change, but there is consensus that it is occurring and that climate deaths will likely occur with increasing frequency in the future. The World Health Organization estimates that since 2004, climate change has accounted for 150,000 deaths.[xl] According to the Climate Vulnerability Monitor published by DARA, a non-profit organization based upon the Spanish word "give" representing cooperative project among 20 developing world governments, estimated 400,000 climate caused deaths occur each year.[xli] According to Oxfam, nearly 1 million deaths will be "indirectly caused" by climate change by 2030.[xlii] To value impacts such as projected loss of life in climate damage models, non-market estimates are required. In the case of climate damage models, the Value of Statistical Life estimate or an equivalent model-specific variable is applied to value this loss of life.

The Ethics of Applying a VSL Estimate

The Value of Statistical Life is an attempt to take empirically observable knowledge about risk reduction preferences and apply this knowledge to understand the economically optimal level of risk to accept. The economic justification of the Value of Statistical life estimate is couched in the ethics of economists who believe that we as a society are better off if we can maximize the size of the economy by avoiding over and under investment in risk reduction. By regulating an activity so that the optimal level of risk is achieved, we are not spending money to over-protect ourselves that could otherwise be spent elsewhere. Conversely, if we are exposing ourselves to too much risk, then the VSL estimate provides a justification to pay for more risk reduction measures. Thus, according to the economic logic, the optimal level of risk reduction minimizes losses and maximizes gains, thereby maximizing the size of the economy which is used as a proxy for overall well-being.

Many of the strongest critics of the use of VSL argue upon non-economic ethical grounds. Kip Viscusi, the economist who first convinced the federal government to begin using VSL estimates for regulations in 1992, outlines many of the criticisms of VSL in an article entitled *The Policy Challenges of* *the Heterogeneity of the Value of Statistical Life.* His basic argument is that applying different VSLs in different situations for different people is economically correct but hard for the public to swallow.[xliii] The most publicized criticism comes when the VSL is lowered because the public perceives this as a devaluing of human life.[xliv] In 2002 a political controversy labeled the "Senior Death Discount" broke out over the ethics of devaluing of the VSLs of senior citizens used in an EPA cost-benefit analysis. Economically speaking, differences in personal VSLs vary according to age, gender, income, and many other factors. The economic rationale for devaluing the VSL of seniors was to account for these differences, but many members of public thought that this approach was immoral and unacceptable. In response to political fall-out, federal agencies now ignore these variations in actual VSLs and use the same VSL for everyone, though the particular VSL estimate varies by agency.[xlv]

Many other factors that create variations in VSL estimates also pose ethical challenges. One is that the level of income strongly affects risk reduction preferences. In 1993 Kip Viscusi argued that the Federal Aviation Administration should apply higher VSL estimates, and thus relatively stronger safety standards, on airlines because the relative income level was higher for airline customers than for other industries.[xlvi] While this makes economic sense, such an approach may not be acceptable to either poorer members of society or those concerned with social justice. Such ethical quandaries regarding application of VSL based upon income rarely emerge domestically due to uniform VSL estimates, but this has major implications for the application of VSL in climate damage models, such as issues that arise when the difference between observed and modeled VSL estimates is significant, and will be examined later in this paper.

Another factor creating variations in VSL estimates that poses an ethical challenge is involvement in labor unions. When economists Kip Viscusi and Joseph Aldy conducted a survey of VSL estimates across the world, they had to add in variables to control for the changes in VSL caused by involvement in labor unions.[xlvii] Historically, labor unions were formed to organize collective bargaining power so that workers could achieve higher wages, and importantly, stronger workplace safety procedures. The idea that an organized group of people with bargaining power can achieve stronger workplace safety measures than individuals seems to imply that a more empowered individual would demand stronger risk-reduction procedures if they had stronger bargaining power to achieve them. This means that the VSL estimates for individuals may be limited to what they imagine as achievable, rather than what they truly want regardless of what is achievable. In theory VSL is the willingness to pay for risk reductions, but if a disempowered individual does not think such risk reduction is possible, then they would not indicate their willingness to pay. Thus variations in VSL may be strongly linked to personal empowerment and bargaining power which are not taken into account in normal VSL analyses.

In response to a growing body of evidence suggesting that environmental risks and harms are disproportionately experienced by minority and low income communities, President Bill Clinton issued Executive Order 12898 to mandate that agencies specifically address the issue of environmental risk distribution when making policy.[xlviii] This was a victory for environmental justice advocates. From a purely economic perspective, these low income and minority communities are choosing to expose themselves to more risk and thus must have a lower Value of Statistical Life than average. The proclamation of the executive order itself is a rejection of this logic and an explicit acknowledgement that forces and ethical frameworks other than economics are necessary to consider in the policy process.

Many people in the environmental justice community also reject the philosophical axioms upon which cost-benefit analyses with VSLs rest. One critical axiom is the Kaldor-Hicks efficiency criterion based is upon the idea of a Pareto improvement. A Pareto improvement occurs when an activity increases overall economic output even when those harmed by an activity are compensated for harm by those who profit from the activity. [xlix] Because of many difficulties associated with assuring these monetary transfers, the Kaldor-Hicks efficiency criterion is used in policy-making. The Kaldor-Hicks criterion states that an outcome that makes everyone better off if total economic output is increased and if those who benefit from a policy *could,* in theory, compensates those harmed by a policy.[l] The transfer of wealth from the beneficiaries to those harmed is not actually required to occur.

To many environmental professionals, the lack of a monetary transfer is inequitable. In a survey administered by public health experts Jessica Lieber, Jonathan Ivey, and Leonard Zwank to 160 environmental justice and risk assessment professionals, a majority of respondents supported a more egalitarian distribution of risk.[li] A majority also indicated that undesirable inequality arising from unequal distribution would likely increase even if wealth transfers were actually made from those who profit to those who are harmed. [lii]This represents a rejection of the idea that Pareto improvements can actually be implemented in a way that does not increase ethically undesirable inequality.

A Rights-Based Approaches to the Value of Statistical Life

So far the examination of the ethics of VSL has focused upon problems the approach itself creates. Other ethical considerations have been raised by those who oppose the use of VSL based upon other moral frameworks.

Lisa Heinzerling, a law professor at Georgetown University, advanced a strong rights-based criticism of applying VSL estimates in her article *The Rights of Statistical People*. Hienzerling argues that the VSL turns real people who are expected to undergo real harm into pre-valued, unidentified, and uncertain “statistical people.” When this occurs the rights of real people to whom real harm befalls have had their rights taken away before they can exercise their right to protect themselves. This, Heinzerling argues, means that regulatory programs make permissible activities that are unacceptable to courts or human morality. As an example she posits that one person is given the right to kill another provided that the activity meets certain cost-benefit analysis requirements. Heinzerling concludes that

> "Describing human lives in statistical terms thus creates the conditions under which human suffering and loss can be conceived of in economic terms, and under which this suffering and loss can be allowed to continue simply because the monetary value we have attached to them is lower than the costs of avoiding them."[liii]

Such rights based approaches are confounded by uncertainty of source of harm and clear causation of injury that the regulatory frameworks in place have been created to address, but nevertheless provide a coherent ethical alternative for policymakers.

Ethical Issues of Applying Global VSL Estimates to Derive the Social Cost of Carbon

From a rights-based perspective, it makes intuitive ethical sense to value every statistical life in a global climate damage model with the same VSL estimate in same way agencies use uniform VSL estimates for regulatory cost-benefit analysis. Everyone one is human and everyone should be valued equally is the logic of this intuitive rights-based approach. The primary economic counter-argument against equal VLS is that such as approach would not adequately take into account variation of VSLs across countries. The ethic of the economic argument is that taking into account and differentiating variations in risk reduction preferences leads to more optimally applied risk reduction resources (i.e. mitigation measures), more overall wealth, and thus a world that is better off. Consistent with this logic, the current Social Cost of Carbon process includes VSL estimates that are for regional and not nation-specific representations of damages in the models (with the exception of some larger nations such as the United States being represented as their own 'region' within DICE and FUND).

The current use of VSL in the SSC process is to endogenously model VSL estimates based solely upon a country's projected per capita income. As stated above, the implicit VSL calculation for DICE is double per capita income multiplied by life expectancy and the calculation for FUND is per capita income multiplied by 200. Modeled VSL estimates are used because the vast majority of nations have not surveyed their citizens about risk. Applying modeled VSLs that are never compared with observed VSL estimates could lead to VSL values being far too low or far too high in the actual models, a proposition examined in detail later.

Modeling the VSL in the Social Cost of Carbon based primarily upon modeled per capita income has the potential to perpetuate global equity problems. While it is much more justifiable to use a nation specific VSL for national policies, it becomes more complicated when applied globally. Modeling and then imposing mortality risk reduction preferences upon neighboring countries to decide the optimal global social cost of carbon is troubling from a rights-based perspective. First, countries with higher incomes automatically have higher VSLs within the current SCC process, regardless of national variation or other choices that would indicate otherwise. Actions taken by other nations to address climate change that surpass the relative efforts of the United States may mean that the relative willingness to pay and hence relative VSL to reduce climate-induced risks is much higher in other nations than for the US, regardless of income. This may be especially true for nations that approach climate change as a human rights issue rather than a problem better addressed with utilitarian philosophy. Second, there is a limited number of quality studies about national VSL estimates. . In a meta-analysis of the entire world's VSL estimates, Joseph and Aldy were only able to critically examine 16 countries. This may be simple lack of data, or it may be because many countries do not explicitly use VSL estimates when making government policy. Thus, we cannot know all the mortality risk preferences, and so must make assumptions in order to apply global policy. The consequence for incorrect modeling means that an increased risk of loss of life is projected as acceptable.

The use of the Kaldor Hicks criterion in the Social Cost of Carbon process in conjunction with modeled VSLs is also morally vexing. The implicit ethical logical of applying modeled, regional-specific VSL estimates with Kaldor Hicks cost-benefit analysis could be summed up as 'American emissions will kill people, the economic activity creating the emissions will increase net welfare, and that the entire world will be better off in this situation even if there is no transfer from the beneficiaries to those harmed.' When benefits disproportionately occur within one nation and harms disproportionately occur within others, the Kaldor Hicks criterion no longer makes moral sense as a philosophical axiom for a cost-benefit analysis or policy making. Economist Thomas Schelling has made an analogous argument that for problems ranging across time and space such as global warming, policy should be based upon actual Pareto improvements. [liv] Pareto improvements occur when the world is made better off by an activity, when those who profit actually, not theoretically, compensate the losers.[lv] The current use of the Kaldor Hicks criterion appears particularly unpalatable given that the majority of climate deaths are projected to occur in the third world where modeled VSL estimates are much lower than in the United States.

Finally, there is the ethical question of applying VSL estimates across time. The ethical framing of this argument is largely based upon whether or not future generations are expected to be richer or poorer than the current generation. Kip Viscusi assumes that future generations will be better off, a proposition accepted and applied in mainstream policy-making. From this vantage point he argues that too much valuation of life now means less money for future generations, hence making future generations worse off. Similarly, he argues that putting more weight on future, unknown VSLs that are likely to be higher than ours means making ourselves worse off to support a future generation that is likely richer. Viscusi directly addresses VSL adjustments in climate policy with utilitarian economic philosophy, arguing that

> "For analyses pertaining to the more distant future, such as analyses of climate change policies or similarly remote environmental problems, the income changes involve future generations rather than those who are currently alive. Making adjustments for differences in income [for VSL] is efficient. However, upward adjustments for future benefit valuations will redistribute income from the poorer current generation to a more affluent future generation, which some may view as inequitable. In response, climate change adherents assert that global warming will make future generations worse off."[lvi]

Martin Weitzman is the straw man "climate change adherent" to whom Viscuis is speaking. He argues that we are exposing future generations to a low probability of catastrophic risks that may cause them to be worse off in the future.[lvii] In a catastrophic scenario, damages of our emissions generating economic activity have the potential to exceed the wealth we generate and pass on to the next generation. Raising values for future generations is a way to hedge for the risk of loss and discontinuity of the assumption of increasing consumption that is driving our current policies. From this vantage point it is more ethical to place higher values on VSL estimates in the future that would appear to be inequitable to Viscusi.

Equity Weighting As A Solution?

Equity weighting in climate damage models has been proposed as one solution to ethical problems that arise from basing the VSL and other key variables upon income. Equity weighting is an methodological attempt to transparently identify value considerations that affect assumptions in climate damage models.[lviii] The importance of equity weights has been concisely summarized by Tol & others:

> " The chosen [equity] perspective is crucially important. Different national decision makers would have different perspectives and choose different equity-weights. Equity-weights therefore do not overcome distributional concerns, or reconcile different positions—equity-weights merely make such concerns explicit."[lix]

The specific methods of equity weighting vary from model to model, but the essential idea is to transparently lay out the variables that are manipulated specifically to address ethical considerations that arise in modeling. The ethics of manipulating specific variables in one way or another are thus explicitly addressed by modelers. Variables included in experimental explorations of equity weightings include risk aversion, inequality aversion, social rate of time preferences (that affects discounting future benefits), and income inelasticity (largely based upon varying income levels). The process has been explored by two of the three climate modelers whose work has been incorporated into the Social Cost of Carbon process: Chris Hope, creator of PAGE, and Richard Tol, creator of FUND.

Unsurprisingly, varying methodologies applied to varying models have led to varying results. In 2002 Chris Hope attempted to apply equity weights to the PAGE model by adjusting for varying income inelasticities and found that this actually *lowered* the Social Cost of Carbon.[lx]

A similar experiment carried was out by Richard Tol and others using FUND and more nuanced techniques in which several more parameters were examined. These modelers came to different conclusions.

> "First, equity-weighted estimates are substantially higher than estimates without equity-weights; equity-weights may even change the sign of the social cost estimates. Second, estimates differ by two orders of magnitude depending on the region to which the equity weights are normalised. Third, equity-weighted estimates are sensitive to the resolution of the impact estimates. Depending on the assumed intraregional income distribution, estimates may be more than twice as high if national rather than regional impacts are aggregated. Fourth, variations in the assumed inequality aversion have different impacts in different scenarios, not only because different scenarios have different emissions and hence warming, but also because different scenarios have different income differences, different growth rates, and different vulnerabilities."[lxi]

Critics of the Social Cost of Carbon process have pointed to the lack of equity weights as a major shortcoming of the SCC estimate because it allows regulator to hide contentious ethical issues in model assumptions rather than making the transparent.[lxii] While equity weighting does make equity assumptions more transparent, weighting also carries other ethical baggage. Equity weighting relies on a Kaldor-Hicks framework and so is not applicable without it and thus is a part of, and not separate from, all the ethical quandaries posed by applying this efficiency criterion. [lxiii] Equity weighting can help to make this implicit ethical logic transparent and can aid policy-markers in minimizing the effects of ethical choices related to income inequality, but it does not address the inherent problem of uncompensated losers.

VSL Representation in the Social Cost of Carbon Analysis

The calculation of the value of a lost life is a component within the damage function of the model. Each of the 3 models applied in the SSC process approaches the calculation of the value of life differently, depending upon the way in which the model approaches overall damages. Below is a description of how the critical value assumption of the value of a statistical life plays a role in each model's overall damage calculation.

DICE 2007

DICE, the Dynamic Integrated Climate and Economy model was developed by William Nordhaus. This model attempts to estimate the optimal growth of the economy based upon marginal costs and marginal benefits explained above.[lxiv] The damage function links overall economic growth with to changes in temperature.[lxv] Emissions reductions are treated as investments that reduce CO2 impact upon the economy. The model calculates many of the damages at a regional level and then aggregates them to derive estimates for the entire global economy.

In Chapter 4 of *Roll the DICE Again: Economic Models of Global Warming*, Nordhaus and Boyer lay out how they approach their calculations of the VSL. The DICE approach to calculating the VSL is based upon a 1996 study examining the health impacts of disease vectors that change due to rising temperatures. The approach does not rely on a standard VSL estimate but upon a related Years of Life Lost estimate. One Year of Life Lost is assumed to be two years of per capita income.[lxvi] To derive the implicit VSL of the DICE model to create a metric comparable to the standard VSL requires multiplying the Years of Life Lost (YLL) by the per capita income of a region and by the country's expected life expectancy.

FUND 2002

FUND, the Climate Framework for Uncertainty Negotiation, and Distribution, was created by Richard Tol. FUND calculates damages for 8 market and non-market sectors and treats economic growth as exogenous. Some damages are triggered by absolute temperature change while others are triggered by rates of change.[lxvii]The FUND model approaches the value of life issue as avoided mortality benefits. Based upon an estimate made in 1992, the FUND model applies 200 times per capita income as the value of an avoided mortality.[lxviii] This metric is appropriate to be used as explicit proxy for a Value of Statistical Life estimate.

PAGE 2002

PAGE, the Policy Analysis and Greenhouse Gas Effect model, was created by Chris Hope. The model examines economic, non-economic, and catastrophic impacts in 8 regions of the world with exogenously modeled economic growth. The damage function is calculated as a fraction of reduced output linked to rising temperatures. Probabilistically modeled catastrophic events can be added as a part of the damage function.

The PAGE 2002 model has a damage function that subtracts the sum of economic and non-economic impacts, such as health impacts, from GDP on a regional basis.[lxix] The PAGE model lacks a simple VSL equivalent and so is not comparable on these grounds.

VSL Estimate in Context

To put each of the estimates for the current VSL in context used in each IAM, the current estimate used by the EPA is $7.4 million in 2006 dollars.[lxx] The United States has a current per capita income of $48,112[lxxi] and the average life expectancy is 78.2 years.[lxxii] A back of the envelope calculation reveals a VSL of $7.5 million applying the DICE approach and $9.6 million for the FUND approach. Because all of the models used in the Social Cost of Carbon process are fully, or at least partially, proprietary, it is not possible to comprehensively analyze the magnitude of effects of various ethical assumptions on the entire social cost of carbon process. This has significant implications for the critical review and revision of IAMs used in the SSC process: it inhibits both public and academic review of critical value assumptions. Importantly, it makes it very difficult to examine the magnitude of effects that critical assumptions have upon the overall outcome of the models.

Comparative Evaluation of VSL Estimates in DICE and FUND with Observed VSL Estimates

Despite the inherent problems associated with comparing across models discussed above, it is still possible to isolate the implicit VSL in two of the three models mentioned above and compare SSC modeled VSL values with independently generated values reported in the literature.

Table 1 is an attempt to "ground truth" DICE and RICE implicit VSL values against 21 VSL estimates from nine countries. The implicit labor market VSLs were taken from a meta-analysis of worldwide VSLs conducted by Kip Vsicusi and Joseph Aldy in 2003[lxxiii] and the per capita income and life expectancy data for DICE and PAGE VSL calculations was taken from the World Bank.[lxxiv,lxxv] Table 2 averages the labor market estimates from each country for comparison to the DICE and FUND models.

The labor market studies examined by Viscusi and Aldy apply a wage-risk analysis approach, where economists determine the level of wage necessary for workers to accept extra risk on a job. Viscusi and Aldy note that while isolating the supply and demand curves is one way to calculate the VSL, the method generally chosen by economists is to locate the area where trade-offs are likely to occur.[lxxvi] The VSL of such labor market studies are often used as proxies for other risks, such as mortality risk related to an environmental pollutant, or, risk related to death caused by a climactic-caused event. While there are many critics who enumerate the problems with the controversial extrapolation of work related risks to environmental risks, this is the general approach applied in federal regulatory analysis.[lxxvii]

Of the 21 studies examined by Viscusi and Aldy, 71% (15) indicate VSL estimates greater than those estimated by PAGE and DICE, 19% (4) fall within the range between DICE and FUND estimates, and 10% (2) were observed in labor market studies to be lower than DICE and FUND estimates. When estimates are averaged as in table 2, 78% (7) are above DICE and FUND estimates, 22% (2) fall below modeled estimates, and no averaged estimates are within the range of DICE or FUND estimates.

Given the lack of correlation of modeled VSL estimates to observed estimates, it is highly likely that the VSL calculation methods of the models could be significantly improved. It is not completely fair to compare single countries because DICE and FUND estimates are calculated on a regional scale. However, although calculations of DICE and FUND are crude compared to the more refined country-level point estimates, they should theoretically at least be in the ballpark of country estimates in a region at rate of higher than 10%. There is also the issue of comparing values endogenously generated in the models with actual data, but still one would expect a closer correlation. It is also possible, but not likely, that these observed point estimates are outliers and that their lack of correlation to DICE and FUND estimates is abnormal.

In order to determine the social cost of carbon, such calculations and estimations are necessary, but critical evaluation of assumptions can improve methodology, ethical consistency, and fairness.

Table 1: Comparison of Labor Market VSL studies with DICE and FUND modeled VSL

Country	Author & Year	Average Income Level of Participants (2000 USD)	Low Estimate of Implicit VSL (millions 2000 USD)	High Estimate of Implicit VSL (millions 2000 USD)	Average Point Estimate of VSL (millions 2000 USD)	Per Capita Income (2000 USD)	DICE (million 2000 USD)	FUND (million 2000 USD)
Australia	Kniesner and Leeth (1991)	$44,863.0	$4.2		$4.2	$21,708.0	$3.4	$4.3
Australia	Miller, Mulvey, and Norris (1997)	$27,177.0	$11.3	$19.1	$15.2			
Austria	Weiss, Maeier, and Gerking (1986)	$12,011.0	$3.9	$6.5	$5.2	$23,974.2	$3.7	$4.8
Canada	Meng (1989)	$43,840.0	$3.9	$4.7	$4.3	$23,559.5	$3.7	$4.7
Canada	Meng and Smith (1990)		$6.5	$10.3	$8.4			
Canada	Cousineau, Lacroix, and Girard (1992)	$23,307.0	$4.6		$4.6			
Canada	Martinello and Meng (1992)	$29,307.0	$2.2	$6.8	$4.5			
Canada	Lanoie, Pedro, and Latour (1995)	$8,125.0	$19.6	$21.7	$20.7			
Canada	Meng and Smith (1999)	$19,962.0	$5.1	$5.3	$5.2			
Hong Kong	Siebert and Wei (1998)	$11,668.0	$1.7		$1.7	$25,756.7	$4.2	$5.2
India	Shanmugam (1996 - 1997)	$778.0	$1.2	$1.5	$1.4	$450.4	$0.1	$0.1
India	Shanmugam (2000)	$778.0	$1.0	$1.4	$1.2			
India	Shanmugam (2001)	$778.0	$4.1		$4.1			
Japan	Kniesner and Leeth (1991)	$29,646.0	$9.7		$9.7	$37,291.7	$6.0	$7.5
South Korea	Kim and Fishback (1993)	$29,665.0	$0.1		$0.1	$11,346.7	$1.7	$2.3
Switzerland	Baranzini and	$47,400.0	$6.3	$8.6	$7.5	$35,639.5	$5.7	$7.1

	Ferro Luzzi (2001)							
Taiwan	Liu, Hammitt, and Liu (1997)	$5,500.0	$0.2	$0.9	$0.6	No Data		
Taiwan	Lisa and Hammit (1999)	$18,483.0	$0.1		$0.1			
UK	Marin and Psacharopoulous (1982)	$14,472.0	$4.2		$4.2	$25,057.6	$3.9	$5.0
UK	Siebert and Wei (1994)	$25,387.0	$9.4	$11.5	$10.5			
UK	Sandy and Elliot (1996)	$16,143.0	$5.2	$69.4	$37.3			

Table 2: Average Observed VSL by Country Compared to DICE and FUND estimates in millions USD (2000 dollars)

Country	Study Averages	DICE	FUND
Australia	$9.7	$3.44	$4.34
Austria	$5.2	$3.74	$4.79
Canada	$7.9	$3.73	$4.71
Honk Kong	$1.7	$4.17	$5.15
India	$2.2	$0.06	$0.09
Japan	$9.7	$6.05	$7.46
South Korea	$0.1	$1.72	$2.27
Switzerland	$7.5	$5.68	$7.13
UK	$22.4	$3.90	$5.01
United States[1]	$7.4 (EPA VSL)	$7.50	$9.60

Income, VSL, India, & Equity

Viscusi and Aldy are quick to point out that a major concern of comparative VSL analyses is the effect of variation in income level upon the final VSL estimate.[lxxviii] Simply put, rich people tend to spend more to mitigate risk of death than poor people. The phenomena of higher incomes leading to higher VSL estimates can be observed in both the labor market studies and the modeled PAGE and DICE estimates.

The income-dependent feature of VSL estimation can be seen most drastically in the gap between the average VSL estimate for India based upon actual labor market studies ($2.2 million) versus the implicit VSL modeled in DICE ($55,503) and FUND ($90,083).

[1] Included as a comparative reference. Estimate is in 2006 $ USD.

The drastic lack in correlation modeled estimates to observed estimates is particularly troubling for several reasons. First, both DICE and FUND have regions that roughly correlate to India. Whereas countries like Austria that are part of another model may affect correlation to a small degree on the regional scale, the lack of correlation for this country is almost certainly present in both models at the regional scale. Second, India makes up a large part of the climate-vulnerable international community, so any problem here means poor modeling for a large portion of the health data of both models. Third, if estimates are so far off in India where there are independently verifiable estimates, this could also be the case for other parts of the developing world where there are not independent VSL estimates. In this case VSL estimates could be significantly skewed.

Table 3 illustrates 3 scenarios in India in which people die due to climate change and their potential difference in representation in a climate damage models. The first scenario, WHO Proportion, uses the World Health Organization estimate of 150,000 deaths a year, assumes that India makes up 1/6th of the world's total population, and portions the annual deaths to India accordingly. The second scenario envisages a minor famine in India in which 100,000 people die as a result of malnutrition induced by climate change, something not too hard to imagine for particularly vulnerable parts of India. The third scenario envisages a catastrophic shift in the Indian summer monsoon pointed out by members of the National Academy of Science as the potential climate tipping point meriting attention from policymakers that has one of the fastest onsets.[lxxix] In this scenario 50,000,000 people are projected to die from malnutrition due to climate change. Results are reported in cost in billions of 2000 US dollars. Costs are also reported as a percentage of global GDP in 2000 to give a ball-park estimate of the magnitude of the effect of a change in VSL on the total global welfare represented in DICE and FUND.

Table 3: Comparison of Climate-Induced Deaths Using FUND, DICE, and Labor Market Average Point Estimates in Billions 2000 USD

Scenario	Deaths		DICE	FUND	Labor Market Average
WHO Proportion	25,000	Cost (Billions 2000 USD)	$1.39	$2.25	$55.00
		% of World GDP in 2000	0.00043%	0.00070%	0.01701%
Minor Famine	100,000	Cost (Billions 2000 USD)	$5.55	$9.01	$220.00
		% of World GDP in 2000	0.00172%	0.00279%	0.06804%
Catastrophic Monsoon Shift	50,000,000	Cost (Billions 2000 USD)	$2,775.18	$4,504.15	$110,000.00
		% of World GDP in 2000	0.85828%	1.39300%	34.01966%

The difference in order of magnitude of costs as a percentage of global GDP for the modeled estimates versus the observed estimate is significant. A climactic event that kills ten thousand or one hundred thousand Indians modeled in DICE or FUND may not significantly affect the economy, but if the model applied observed VSL estimates, then this could push up the social cost of carbon, if only incrementally.

However, this analysis could be extrapolated to the rest of the developing world. Four assumptions would have to be met to make this extrapolation. First, it must be assumed that in Africa and the rest of the developing world that DICE and FUND VSL estimates are significantly lower than what would be observed using a labor market study, an assumption that appears reasonable given the above analysis. Second, it must be assumed that the majority of climate-induced deaths occur in the developing world. Third, it must be assumed that the rest of the developing world has a similar observable VSL as India. Fourth, it must be assumed that the World Health Organization estimate of 150,000 climate-related deaths is correct and represented in the model accurately. If these assumptions are met, then the new resulting damage to the world economy would be above 0.1% of global GDP, as opposed to the 0.002% order of magnitude predicted by DICE and FUND. In the case of this order of magnitude, it is not unreasonable to project the Social Cost of Carbon rising a few cents (10-30 cents) in each of the models. Such accounting for projected death is negligible given the large uncertainty in the Social Cost of Carbon estimate.

Limitations of Methodology

As can be observed in Table 3, VSL becomes more important depending upon how many climate induced deaths occur. All three models used in the Social Cost of Carbon analysis use different parameters to determine how many people die due to climate change. Thus key determinants of the magnitude of effect of the VSL estimate are the underlying health assumptions. Some of these assumptions and damage formulations, such as the 1996 disease vector study applied in DICE,[lxxx] are based upon assumptions from studies in the 1990s when DICE, PAGE, and FUND were under development. If updated health studies assume more climate-related deaths are used to reformulate corresponding damage calculations, then updating these assumptions in conjunction with updating the VSL could make the estimate an even more important part of the model.

There are several fundamental issues with this approach, some of which are described here. First, the resolution of both FUND and DICE are on regional scales and not on scales of single nations. The aggregation of VSL on regional scales makes comparing labor market point estimates and modeled point estimates difficult. Second, the labor market studies are all based upon varying assumptions that may make them difficult to compare to one another, let alone to other modeled data. Third, at least part of the VSL calculation in FUND and DICE is determined by variables endogenous to the models. That is, the model predicts and projects the conditions that lead to economic growth over time that in turn affect VSL calculations. Finally, the income levels in the labor studies are based upon the income of participants and not based upon per capita income that is used in model calculations. Averaging observed data merely compounds these problems.

While there are problems with assumptions and oversimplification in this approach, they have been used before to compare global VSL estimates. Taken in the context of social cost of carbon modeling, the approach is at least justifiable as one of the few methods to compare modeled data with observed data for evaluation of critical equity assumptions. It's not easy to derive a national VSL, even harder to derive global VSL estimates, and harder still to compare these estimates across the many confounding geographic and cultural variables, but this is what the models are doing when computing the VSL.

Catastrophic Damages and the Value of Statistical Life

As noted in the Social Cost of Carbon report, the SSC estimate does not adequately take into account the potential low-probability risk of catastrophic damages such as the melting of the polar ice caps. The underlying models also do a poor job of taking into account the slightly higher risk of less-than-catastrophic but still devastating climate induced events. In the scenario of a climate induced catastrophe, very large loss of life is expected. When a large loss of life is projected to occur, the VSL estimate suddenly takes on significantly more importance in climate damage models and economic decision-making.

The monsoon shift in India illustrated in table x can serve as an example. In this scenario climate change causes a shift in seasonal wind patterns over India that leads to a famine killing 100 million people. Depending upon the VSL used, you could have an event that registers with an effect of 1% on the global economy with modeled VSL results or one that registers as the loss of 1/3 of the entire global economy if you use observed VSL estimates. If either more people died in India, or if the VSL was even higher, or if 100 million people were projected to die in a country with a higher VSL, then of course this percentage would be higher. This potentially rising percentage means that it is possible to model low-probability events that are worth more for us to avoid than the entire net worth of the global economy. For instance, if a similar climate-induced catastrophic event occurred in the US that claimed 100 million lives, then the estimated loss to the global economy would be around $740 trillion dollars, several times higher than current global GDP estimates. This estimate does not include market damages which would likely be significantly lower.

Climate economists Martin Weitzman and William Nordhaus have both pointed out that these low probability, high impact events can dominate traditional cost-benefit analyses if they are included in the SCC estimate.[lxxxi,lxxxii] Because the expected value of a catastrophic event is so high (perhaps even higher than the entire global economy) and because scientists indicate that such events are possible due to global warming, then accounting for these events as possible states of a future world indicate that we should put an exorbitantly high price-tag on the social cost of carbon. This has led some economists, including Nordhaus and Weitzman, to ask whether cost-benefit analysis used in the SCC estimate, upon which any federal climate policies will likely be based, is an adequate method of approaching the climate problem.

The current implied consensus is that policymakers can use CBA up to a point to make policy, but when catastrophe is incorporated, the exorbitantly high SCC estimate achieved when incorporating the possibility of catastrophic damages means that the tool is no longer useful for policymakers. Practically, policymakers accept $21 per ton of CO^2 as valid, but $1,000 per ton of CO^2 to avoid a catastrophic risk becomes an absurd policy prescription. The current solution to this problem is to omit catastrophic damages. The firm point of where the tool becomes absurd versus where the tool is applicable for policymaking is a grey area.

What breaks the CBA tool in catastrophic situations? As illustrated above, in many potential catastrophic situations, the damages calculated with non-market factors such as VSL estimates can sum and surpass the total value of global utility. The more damage done to non-market goods, including human lives, the more important non-market factors become. Thus, from a purely economic lens, determining the threshold of acceptable catastrophic risk exposure is fundamentally based upon how policymakers choose to value non-market factors.

Applying this insight helps to narrow in on exactly where the SCC process and economic models begin to offer absurd or unacceptable results. Any point where non-market value such as the value of those who died exceeds global utility is, very difficult to model accurately and base policy upon. . This is because an event that affects the world economy more through non-market means than through market means when considered in an economic model will almost certainly be highly questionable due to valuation techniques. While the situation of non-market value exceeding global utility may apply just to catastrophic events, the same logic could apply to situation could apply to much smaller scale events like high impact, non-catastrophic devastating natural disasters. This means that the fundamental threshold for the usefulness of the climate damage models is very low: only very small events can be accurately modeled. Larger catastrophic events are considered, the usefulness of the models as policymaking tool begin to break down due to non-market valuation.

If the adequacy of the cost-benefit tool enjoys continual acceptance and application as a valid means of addressing the global warming problem (as it currently is by US policymakers), then VSL estimates and other non-market will become very important when evaluating catastrophic risks to the global economy.

International & Domestic Policy Considerations

If federal agencies begin to make stronger American contributions to the global effort to reduce greenhouse gas emissions, then the magnitude of the policy will likely be determined by the SCC estimate. All of the policies will also contain within them the many unexamined ethical assumptions made by the modelers to whom ethical decision-making power was deferred. All policies aimed at reducing greenhouse gases are unavoidably international policies and will likely be promulgated in international fora as a way to demonstrate American commitment to addressing climate change. Thus, potential climate policies using the SSC estimate should be considered in an international context.
The current dominant forum for international climate negotiations is the United Nations Framework Convention on Climate Change (UNFCCC). A key feature of the UNFCCC is an explicit emphasis and incorporation of equity considerations, particularly those arising from the differing income levels of member nations. In this context is reasonable to assume that policies may be subjected to methodological scrutiny to reveal ethical assumptions.

In the UNFCCC and other international arenas, American negotiators emphasizing climate policies enacted by federal agencies will have to contend with actors attempting to gain better negotiating positions. The significant ethical baggage of nonmarket valuation techniques may become a liability for American negotiators, especially because equity has been explicitly excluded from the conversation. This is particularly true for the current practice of applying various modeled Value of Statistical Life estimates for world regions that are dependent largely upon income.

Developing nations often apply equity concerns about past historical emissions and responsibility to act to address climate change as a way to gain a better negotiating position in the UNFCCC. It is highly likely that developing nations will oppose the current American VSL approach and argue for their citizens to be considered in American climate policies in other ways. Certain developing nations may also frame VSL variations as a "smoking gun" that proves America's lack of concern for their citizens. While there may be sound economic counterarguments to back up the current American VSL approach, such counterarguments would be immensely difficult to advance in a forum where economic argument are explicitly weighed against ethical considerations that take into account countries' varying levels of wealth.

The federal action that will have the biggest impact on total American CO^2 emissions currently under consideration is regulating existing stationary CO^2 emissions sources. This action would be undertaken by the EPA under section 111(d) of the Clean Air Act and its possible magnitude of effect upon CO^2 emissions would be partially determined by the Social Cost of Carbon estimate applied.[lxxxiii] If this policy is enacted, then it is highly likely that the US will not significantly change the regulatory framework, including the Social Cost of Carbon methodology, for at least a few years, barring court verdicts or legislation, to provide some stability to transitioning industry. In this case the largest piece of

US climate policy would have embedded ethical considerations that may prove to be a liability for the US in negotiating a favorable international agreement.

One final consideration is that the Clean Air Act contains a provision for reciprocity of air pollution reduction policies that affect foreign nations if they also put similar policies into place.[lxxxiv] Specifically, the provision allows the EPA Administrator to impose actions to address global air pollution to the extent that some other foreign power also undertakes analogous actions. Thus, if other foreign powers use a higher social cost of carbon to formulate policy or use higher implicit VSL estimates for the US and other countries that results in stronger policies relative to American policy, then it may be legally possible for the EPA Administrator to make top-down changes to US regulations pertaining to climate policy on the grounds of reciprocity.

Conclusion

There are many issues associated with using modeled Value of Statistical Life estimates in the Social Cost of Carbon that have implications for the economic and ethical outcomes of climate policies. Many of these issues have gone unexamined due to deference to experts. While such deference was justified at the time of its creation on the grounds of reasonable expediency to produce a concrete deliverable, it has created potential for error prorogation and avoidable moral hazards. If the Social Cost of Carbon is to be used to develop more impactful and permanent policy such as the regulation of stationary fossil fuel plants, then the estimate should be thoroughly reviewed.

There are several ways to improve the Social Cost of Carbon process and estimate in light of this analysis. Comparing observed values from literature versus modeled values from climate damage models is not a simple task but it is necessary to check the validity of approaches and assumptions. A more thorough analysis should include proprietary impact information from the models. Additionally, calculating intermediate damage variables such as projected lives lost or projected acres of ecosystem destroyed is one way to make it simpler to compare nonmarket damages across models and with independent research. This would also allow for better communication of impacts and allow for a more collaborative and transparent approach to the Social Cost of Carbon process. Developing methods to define contingently valued non-market goods in non-economic terms is especially relevant given the controversy surrounding contingency valuation.

Defining non-market goods in non-economic terms also allows for a more sensible approach to catastrophic risks. Non-market damages can easily exceed market damages in scenarios of catastrophe. Currently, catastrophic risk is omitted from the Social Cost of Carbon. Defining non-market goods in non-economic terms such as the projected lives lost and other non-market indicators is more relevant to policymakers than the astronomically high economic costs of catastrophic events. This approach would allow policy makers to use the utilitarian method of cost-benefit analysis when it works and to switch to other policy frameworks when cost-benefit analysis fails.

The ethical framework upon which the Social Cost of Carbon and the Value of Statistical Life estimates are based should be explicitly examined and communicated to decision makers. Underlying philosophical axioms, such as the Kaldor-Hicks efficiency criterion, and the potential problems associated with applying these axioms to global policies should be more thoroughly examined. The political implications and liability of the United States in global climate negotiations arising from the application of non-uniform, non-rights-based, utilitarian estimates of mortality reduction should be clarified for decision makers and diplomats. Alternative viewpoints such as rights-based and environmental justice approaches should be considered when valuing carbon, especially when catastrophic risk poorly explained by utilitarian cost-benefit analysis is considered. In the longer term, special attention should be paid by to behavior that does not fit the utilitarian ethical framework, such as voluntary emissions reductions by countries not bound by the Kyoto Protocol.

To echo statements made by the economist Martin Weitzman, the most important recommendation by far is more humility. Economically valuing climate change is essentially valuing what we have plus our economy and subtracting what we think we might lose as the world warms. Fundamentally, we do not know the value of what we have, economically or otherwise, and we are guessing at what we may lose with the caveat that we may lose a lot more than we think. Our attempts to universally value what we have are crude, and myopic compared to timescale, diversity, and magnitude of what we are trying to value.

Without computers, which are only a few years older than the valuation methods themselves, this undertaking would not be even remotely conceivable. In a world without such powerful computers where we understood the risks as well as we do now, attempting to apply a complex cost-benefit analysis to come as close to as possible to triggers of catastrophic risk without crossing the invisible tipping-point line would be impossible. Without computers, applying a crude utilitarian philosophy in cost-benefit analysis to argue that we must minimize how much carbon we reduce now to protect overall economic output and hence human well-being would be untenable. Without computers, we would be forced to rely on other ethical frameworks to make decisions about climate policy.

We do not live in this fictional world without computers. Instead we have access to vast computational capacity, complex utilitarian valuation methods, and climate damage models to help make sense of it all. This affords us the ability to use utilitarian tools to help make smarter decisions about climate policy. Yet, to rely only upon imperfect and incomplete cost-benefit analysis to inform climate policy is just as foolish in a world where it is possible as where it is not. Currently, we have thousands of well educated guesses about particular nuances in the future state of the world. We use models to project these assumptions across time, and from the data we create and collect based upon our assumptions about the future of the world. We analyze our economic echoes and decide upon a price to place on carbon.

In situations involving inter-generational equity and the projection of global power, we should be particularly mindful of the ethical values that we apply to solve problems. We are a rights-based society and one of our primary foreign policy objectives is to support the emergence of more rights-based governance. The values applied in our current Social Cost of Carbon estimate are not rights-based and are inherently global in nature. If we project utilitarian assumptions across time and space through climate policies, we should not be surprised if eventual outcomes offend advocates of rights-based governance.

Footnotes

[i] Massachusetts, et al. Petitioners v. Environmental Protection Agency, et al. 22 Ill.549 U.S. 497, 127 S. Ct. 1438, 167 L. Ed. 2d 248, 63 ERC 2057, 2007. http://www.oyez.org/cases/2000-2009/2006/2006_05_1120

[ii] Ibid.

[iii] Center for Biological Diversity v. NHTSA, 538F.3d 1172, 1200; 9th Cir., 2008. http://graphics8.nytimes.com/packages/pdf/business/20071116_fuel_decision.pdf

[iv] Ibid.

[v] Ibid

[vi] "Executive Order 12866—Regulatory Planning and Review" The Federal Register. 4 October 1993. http://www.plainlanguage.gov/populartopics/regulations/eo12866.pdf

[vii] Social Cost of Carbon Supporting Technical Documents. http://www.epa.gov/otaq/climate/regulations/scc-tsd.pdf

[viii] "The Social Cost of Carbon: Estimating the Benefits of Reducing Greenhouse Gas Emissions" US Environmental Protection Agency. http://www.epa.gov/climatechange/EPAactivities/economics/scc.html

[ix] Bell, Ruth Greenspan & Callan, Dianne. "More than Meets the Eye: The Social Cost of Carbon in U.S. Climate Policy in Plain English" WRI. http://pdf.wri.org/more_than_meets_the_eye_social_cost_of_carbon.pdf

[x] Climate Change. Regulatory Initiatives. EPA. http://www.epa.gov/climatechange/EPAactivities/regulatory-initiatives.html#stationary

[xi] "Remarks by the President of the United States" The Whitehouse. Retrieved from http://www.whitehouse.gov/the-press-office/2013/02/12/remarks-president-state-union-address

[xii] Aaheim, A., & M. Hoel, S.W. Hong, P. Meier, M. Munasinghe. "Applicability of Techniques of Cost-Benefit Analysis to Climate Change" United Nations Intergovernmental Panel on Climate Change. Second Assessment Report. *IPCC Working Group III,* Chapter 5. 1996.

[xiii] Ibid.

[xiv] ibid.

[xv] Ibid.

[xvi] " Technical Support Document :Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 1286. Interagency Working Group on Social Cost of Carbon, United States Government. February 2010.

[xvii] Ibid.

[xviii] Ibid.

[xix] Ibid.

[xx] Ibid.

[xxi] Ibid.

[xxii] Ibid.

[xxiii] Frankenhauser, Samuel, Tol, Richard." On the representation of impact in integrated assessment models of climate change". *Environmental Modeling and Assessment* . Vol. 3 (1998) 63–74. http://link.springer.com/content/pdf/10.1023%2FA%3A1019050503531.pdf

[xxiv] " Technical Support Document :Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 1286. Interagency Working Group on Social Cost of Carbon, United States Government. February 2010

[xxv] Bell, Ruth Greenspan. "The Social Cost of Carbon and Climate Change." *World Resources Institute.* 13 July 2011. http://www.wri.org/stories/2011/07/social-cost-carbon-and-climate-change-policy

[xxvi] "Contingent Valuation." US Environmental Protection Agency. Center for Environmental Economics. http://yosemite.epa.gov/ee/epalib/ord1.nsf/8e2804a29538bbbf852565a500502e9e/5f888b3c473da662852565a5006c5711

[xxvii] Spash, Clive L. "Multiple Value Expression in Contingent Valuation: Economics and Ethics" *Environmental Science and Technology*. Vol. 8: 34. 8 November 2000. http://pubs.acs.org/doi/pdf/10.1021/es990729b

[xxviii] Nordhaus, William, Boyer, Joseph. Roll the DICE Again: Economic Models of Global Warming. Chapter 4. Yale University. 25 October 1999.

[xxix] Hanemann, Michael. "Nonmarket Impacts" Presentation to the EPA on Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis: Modeling Climate Change Impacts and Associated Economic Damages. January 2011. http://yosemite.epa.gov/ee/epa/eerm.nsf/vwRepNumLookup/EE-0564?OpenDocument

[xxx] Ibid.

[xxxi] Frankenhauser, Samuel, Tol, Richard." On the representation of impact in integrated assessment models of climate change". *Environmental Modeling and Assessment* . Vol. 3 (1998) 63–74. http://link.springer.com/content/pdf/10.1023%2FA%3A1019050503531.pdf

[xxxii] Hanemann, Michael. "Nonmarket Impacts" Presentation to the EPA on Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis: Modeling Climate Change Impacts and Associated Economic Damages. January 2011.

[xxxiii] "Frequently Asked Questions on Mortality Risk Valuation" US Environmental Protection Agency. National Center for Environmental Economics. http://yosemite.epa.gov/ee/epa/eed.nsf/pages/MortalityRiskValuation.html
[xxxiv] Ibid.
[xxxv] Ibid.
[xxxvi] "Wage Differentials" US Environmental Protection Agency. National Center for Environmental Economics. http://yosemite.epa.gov/ee/epalib/ord1.nsf/6be791b641c9d5ae852567840015b65f/2be78e28bf9bf4ea852565a5006c440b!OpenDocument
[xxxvii] "Stated Preferences" US Environmental Protection Agency. National Center for Environmental Economics. http://yosemite.epa.gov/ee/epalib/ord1.nsf/22dcaad1f2bc15e8852567840015b4f6/59fecab0c8a36148852565a5006c4ef1!OpenDocument
[xxxviii] "Valuing Mortality Risk Reductions for Environmental Policy: A White Paper" US Environmental Protection Agency, National Center for Environmental Economics. 10 December 2010.
[xxxix] "Frequently Asked Questions on Mortality Risk Valuation" US Environmental Protection Agency. National Center for Environmental Economics. http://yosemite.epa.gov/ee/epa/eed.nsf/pages/MortalityRiskValuation.html
[xl]"Climate Change." *World Health Organization.* The Health and Environment Linkages Initiative. http://www.who.int/heli/risks/climate/climatechange/en/
[xli]"Climate Vulnerability Monitor: A Guide to The Cold Calculus of A Hot Planet." DARA. 2012. http://www.daraint.org/wp-content/uploads/2012/10/CVM2-Low.pdf.
[xlii]"Oxfam and climate change" Oxfam International. http://www.oxfam.org/en/grow/oxfam-and-climate-change
[xliii] Viscusi, Kip. "Policy Challenges of the Heterogeneity of the Value of Statistical Life." *Foundations and Trends in Micro Economics*. 2000.
[xliv] Ibid.
[xlv] Ibid.
[xlvi] Ibid.
[xlvii] Viscusi WK, Aldy JE. The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. Journal of Risk and Uncertainty. 2003;27:5-76.
[xlviii]"Symposium on Integrating the Science of Environmental Justice into Decision-Making at the Environmental Protection Agency: An Overview" US Environmental Protection Agency.31 August 2011. http://ajph.aphapublications.org/doi/full/10.2105/AJPH.2011.300368
[xlix] "Pareto Improvements and the Kaldor-Hicks Criterion." Reckon LLP. http://www.reckon.co.uk/open/Pareto_improvements_and_Kaldor-Hicks_efficiency_criterion
[l] Ibid.
[li] Ivey, Jonathan, Lieber, Jessica, & Zwank, Leonard. "Agreement with inequality axioms and perceptions of inequality among environmental justice and risk assessment professionals. Health, Risk & Society Vol. 11, No. 1, February 2009, 55–69.
[lii] Ibid
[liii] Hienzerling, Lisa. "The Rights of Statistical People" Georgetown University Law Center. 2000.
[liv] Schelling, Thomas C. "Intergenerational Discounting" *Energy Policy*. Volume 23 Number 4/5 1995.
[lv] "Pareto Improvements and the Kaldor-Hicks Criterion." Reckon LLP. http://www.reckon.co.uk/open/Pareto_improvements_and_Kaldor-Hicks_efficiency_criterion
[lvi] Viscusi, Kip. "Policy Challenges of the Heterogeneity of the Value of Statistical Life." *Foundations and Trends in Micro Economics*. 2000.
[lvii] Martin L. Weitzman, Some Basic Economics of Extreme Climate Change (Draft, 2009).
[lviii] Ibid.
[lix] Anthoff, David, Hephburn, Cameron, Tol, Richard. "Equity weighting and the marginal damage costs of climate change" *Ecological Economics*. Vol. 68 (836-849). 2009.
[lx] Hope, Chirs. "Discount Rates, Equity Weights and the Social Cost of Carbon" Energy Economics Volume 30 (1011-1019) 2008.
[lxi] Anthoff, David, Hephburn, Cameron, Tol, Richard. "Equity weighting and the marginal damage costs of climate change" *Ecological Economics*. Vol. 68 (836-849). 2009.
[lxii] Hope, Chirs & Johnson, Laurie. "The Social Cost of Carbon in US Regulatory Analysis: An Introduction and Critique." September 2012. Journal of Environmental Studies and Sciences. Vol 2 (3). pp 205-221. http://link.springer.com/content/pdf/10.1007%2Fs13412-012-0087-7.pdf
[lxiii] Anthoff, David, Hephburn, Cameron, Tol, Richard. "Equity weighting and the marginal damage costs of climate change" *Ecological Economics*. 2009. Vol. 68 (836-849).
[lxiv] " Technical Support Document :Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 1286. Interagency Working Group on Social Cost of Carbon, United States Government. February 2010.
[lxv] Ibid.

[lxvi]Nordhaus, William, Boyer, Joseph. Roll the DICE Again: Economic Models of Global Warming. Chapter 4. Yale University. 25 October 1999.

[lxvii] " Technical Support Document :Social Cost of Carbon for Regulatory Impact Analysis Under ExecutiveOrder 1286. Interagency Working Group on Social Cost of Carbon, United States Government. February 2010

[lxviii] Anthoff, David, Tol, Richard. "FUND - Climate Framework for Uncerainty, Negotiation, and Distribution" 4 November 2010. http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0564-101.pdf/$file/EE-0564-101.pdf

[lxix] " Technical Support Document :Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 1286. Interagency Working Group on Social Cost of Carbon, United States Government. February 2010.

[lxx] "Frequently Asked Questions on Mortality Risk Valuation" US Environmental Protection Agency. National Center for Environmental Economics. http://yosemite.epa.gov/ee/epa/eed.nsf/pages/MortalityRiskValuation.html

[lxxi] "GDP per capita (Current US$)" The World Bank. Data. http://data.worldbank.org/indicator/NY.GDP.PCAP.CD

[lxxii] "Life expectancy at birth, total (years)" The World Bank. Data. http://data.worldbank.org/indicator/SP.DYN.LE00.IN

[lxxiii] Viscusi WK, Aldy JE. The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. Journal of Risk and Uncertainty. 2003;27:5-76.

[lxxiv] "GDP per capita (Current US$)" The World Bank. Data. http://data.worldbank.org/indicator/NY.GDP.PCAP.CD

[lxxv] "Life expectancy at birth, total (years)" The World Bank. Data. http://data.worldbank.org/indicator/SP.DYN.LE00.IN

[lxxvi] Viscusi WK, Aldy JE. The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. Journal of Risk and Uncertainty. 2003;27:5-76.

[lxxvii] Ibid

[lxxviii] Ibid

[lxxix] Hall, Jim, Hermann Held, Elmar Krigler,Timothy M. Lenton, Wolfgang Lucht, & Stefan Rahmstorf.*†, Hermann "Tipping elements in the Earth's climate system" Proceedings of the National Academy of Science. 2007.

[lxxx] Nordhaus, William, Boyer, Joseph. Roll the DICE Again: Economic Models of Global Warming. Chapter 4. Yale University. 25 October 1999.

[lxxxi] Martin L. Weitzman, Some Basic Economics of Extreme Climate Change (Draft, 2009).

[lxxxii] William D. Nordhaus, The Economics of Tail Events With An Application to Climate Change, 5 Rev. Envtl. Econ. & Pol'y 240 (2011).

[lxxxiii] Gregory E. Wannier, Jason A. Schwartz, Nathan Richardson, Michael A. Livermore, Michael B. Gerrard, and Dallas Burtraw "Prevailing Academic View on Compliance Flexibility Under 111 of the Clean Air Act". Resources for the Future. July 2011.

[lxxxiv] Nash, Jonathan Remy. "The Curious Legal Landscape of the Extraterritoriality of U.S. Environmental Laws". Virginia Journal of International Law. Vol 50:4. P. 997. 2010.

References

Aaheim, A., & M. Hoel, S.W. Hong, P. Meier, M. Munasinghe. “Applicability of Techniques of Cost-Benefit Analysis to Climate Change” United Nations Intergovernmental Panel on Climate Change. Second Assessment Report. IPCC Working Group III, Chapter 5. 1996

Anthoff, David, Hephburn, Cameron, Tol, Richard. “Equity weighting and the marginal damage costs of climate change” Ecological Economics. Vol. 68 (836-849). 2009.

Anthoff, David, Tol, Richard. “FUND - Climate Framework for Unceraintry, Negotiation, and Distribution” 4 November 2010. http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0564-101.pdf/$file/EE-0564-101.pdf

Bell, Ruth Greenspan. “The Social Cost of Carbon and Climate Change.” World Resources Institute. 13 July 2011. http://www.wri.org/stories/2011/07/social-cost-carbon-and-climate-change-policy

Center for Biological Diversity v. NHTSA, 538F.3d 1172, 1200; 9th Cir., 2008.

“Climate Change.” World Health Organization. The Health and Environment Linkages Initiative. http://www.who.int/heli/risks/climate/climatechange/en/

“Climate Vulnerability Monitor: A Guide to The Cold Calculus of A Hot Planet.” DARA. 2012. http://www.daraint.org/wp-content/uploads/2012/10/CVM2-Low.pdf.

“Contingent Valuation.” US Environmental Protection Agency. Center for Environmental Economics. http://yosemite.epa.gov/ee/epalib/ord1.nsf/8e2804a29538bbbf852565a500502e9e/5f888b3c473da662852565a5006c5711

“Executive Order 12866—Regulatory Planning and Review” The Federal Register. 4 October 1993. http://www.plainlanguage.gov/populartopics/regulations/eo12866.pdf

Frankenhauser, Samuel, Tol, Richard.” On the representation of impact in integrated assessment models of climate change”. Environmental Modeling and Assessment . Vol. 3 (1998) 63–74. http://link.springer.com/content/pdf/10.1023%2FA%3A1019050503531.pdf

“Frequently Asked Questions on Mortality Risk Valuation” US Environmental Protection Agency. National Center for Environmental Economics.

Gregory E. Wannier, Jason A. Schwartz, Nathan Richardson, Michael A. Livermore, Michael B. Gerrard, & Dallas Burtraw. “Prevailing Academic View on Compliance Flexibility Under 111 of the Clean Air Act”. Resources for the Future. July 2011.

“GDP per capita (Current US$)” The World Bank. Data. http://data.worldbank.org/indicator/NY.GDP.PCAP.CD

Hall, Jim, Hermann Held, Elmar Krigler, Timothy M. Lenton, Wolfgang Lucht, & Stefan Rahmstorf.*†, Hermann “Tipping elements in the Earth’s climate system” Proceedings of the National Academy of Science. 2007.

Hanemann, Michael. “Nonmarket Impacts” Presentation to the EPA on Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis: Modeling Climate Change Impacts and Associated Economic Damages. January 2011. http://yosemite.epa.gov/ee/epa/eerm.nsf/vwRepNumLookup/EE-0564?OpenDocument

Hienzerling, Lisa. “The Rights of Statistical People” Georgetown University Law Center. 2000.

Hope, Chirs. “Discount Rates, Equity Weights and the Social Cost of Carbon” Energy Economics Volume 30 (1011-1019) 2008.

Hope, Chirs & Johnson, Laurie. “The Social Cost of Carbon in US Regulatory Analysis: An Introduction and Critique.” September 2012. Journal of Environmental Studies and Sciences. Vol. 2 (3). pp 205-221. http://link.springer.com/article/10.1007%2Fs13412-012-0087-7

Ivey, Jonathan, Lieber, Jessica, & Zwank, Leonard. “Agreement with inequality axioms and perceptions of inequality among environmental justice and risk assessment professionals.” Health, Risk & Society Vol. 11, No. 1, February 2009, 55–69.

“Life expectancy at birth, total (years)” The World Bank. Data. http://data.worldbank.org/indicator/SP.DYN.LE00.IN

Martin L. Weitzman, Some Basic Economics of Extreme Climate Change (Draft, 2009).

Nash, Jonathan Remy. “The Curious Legal Landscape of the Extraterritoriality of U.S. Environmental Laws”. Virginia Journal of International Law. Vol 50:4. P. 997. 2010.

Nordhaus, William, Boyer, Joseph. *Roll the DICE Again: Economic Models of Global Warming*. Chapter 4. Yale University. 25 October 1999.

Nordhaus, William D. “The Economics of Tail Events With An Application to Climate Change, 5 Review of Environmental Economics and Policy.” Vol. 5 (2). P. 240-257. 2011. http://reep.oxfordjournals.org/content/5/2/240.full

"Pareto Improvements and the Kaldor-Hicks Criterion." Reckon LLP. http://www.reckon.co.uk/open/Pareto_improvements_and_Kaldor-Hicks_efficiency_criterion

"Symposium on Integrating the Science of Environmental Justice into Decision-Making at the Environmental Protection Agency: An Overview" US Environmental Protection Agency.31 August 2011. http://ajph.aphapublications.org/doi/full/10.2105/AJPH.2011.300368

"Technical Support Document :Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 1286. Interagency Working Group on Social Cost of Carbon, United States Government. February 2010

Viscusi, W. Kip and Aldy, Joseph E., "The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World" (2002).Harvard Law School John M. Olin Center for Law, Economics and Business Discussion Paper Series.Paper 392. http://lsr.nellco.org/harvard_olin/392

Viscusi, Kip. "Policy Challenges of the Heterogeneity of the Value of Statistical Life." *Foundations and Trends in Micro Economics*. 2000.