October 20, 2020

Via Email to ClimateAct@dec.ny.gov

To: Jason Pandich, Climate Analyst 1, New York Department of Environmental Conservation

Re: Draft Guidance from the New York Department of Environmental Conservation on the Value of Carbon

Dear Mr. Pandich,

The Institute for Policy Integrity at New York University School of Law (Policy Integrity)[1] respectfully submits this letter on the value of carbon for the consideration of the New York Department of Environmental Conservation (DEC or the Department). Policy Integrity understands that DEC has been tasked with developing a social cost of carbon for use by New York state agencies and wishes to provide its expertise while DEC is still developing a draft of its guidance. Policy Integrity is a non-partisan think tank dedicated to improving the quality of government decisionmaking through advocacy and scholarship in the fields of administrative law, economics, and public policy. Policy Integrity regularly advises federal and state agencies on the social cost of carbon.

We thank you for your consideration.

Respectfully,

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[1] This document does not purport to present the views of New York University School of Law, if any.

Introduction

Policy Integrity is an expert on the Social Cost of Carbon (SCC), including its application in state-level decisionmaking. Policy Integrity has provided testimony and public comments to multiple federal and state regulators on how they can appropriately apply the SCC and why they should use the 2016 Interagency Working Group (IWG) estimates. We have provided advice on the SCC to numerous states: California, Colorado, Connecticut, Georgia, Iowa, Minnesota, Nevada, New Jersey, New Mexico, New York,[2] Oregon, Virginia, and Wisconsin.[3]

Policy Integrity has produced original scholarship and guidance materials on the SCC. The original scholarship of our staff covers issues such as omitted damages from the IWG social cost estimates,[4] the legal and economic rationale for using a global estimate of climate damages,[5] and meta-analysis[6] and expert elicitations of global climate damages.[7] Of particular interest to the DEC may be the October 2017 report, *The Social Cost of Greenhouse Gases and State Policy*,[8] which is a guide for state-level decisionmakers.

Policy Integrity's expertise has been recognized by others. Policy Integrity's work has been cited by the IWG[9] and the National Academies of Sciences, Engineering, and Medicine (NAS),[10] as well as many other scholars and institutions. Policy Integrity's comments were cited by the New York State PSC in its Clean Energy Standard Final Order.[11] Of additional relevance to decisionmakers in the Tri-State area, Policy Integrity was invited to give expert testimony on the SCC before the New Jersey state legislature.[12]

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[2] *See* Appendix A: List of Policy Integrity Comments to New York State Regulators.

[3] See Policy Integrity's *Policy Impacts*, https://policyintegrity.org/policy-impacts, for more information on our work on the social cost of carbon; see also our website, policyintegrity.org, for our public comments and testimonies on the social cost of carbon.

[4] PETER HOWARD, INST. FOR POL'Y INTEGRITY, OMITTED DAMAGES: WHAT'S MISSING FROM THE SOCIAL COST OF CARBON (2014), https://policyintegrity.org/publications/detail/omitted-damages-whats-missing-from-the-social-cost-of-carbon.

[5] Peter Howard & Jason Schwartz, *Think Global: International Reciprocity as Justification for a Global Social Cost of Carbon*, 42 COLUM. J. ENV'T L. 203 (2017), https://policyintegrity.org/files/publications/Think_Global.pdf.

[6] Peter Howard & Thomas Sterner, *Few and Not So Far Between: A Meta-analysis of Climate Damage Estimates*, 68 ENV'T & RES. ECON. 197, https://link.springer.com/article/10.1007/s10640-017-0166-z.

[7] Peter Howard & Derek Sylvan, *Wisdom of the Experts: Using Survey Responses to Address Positive and Normative Uncertainties in Climate-Economic Models*, CLIMATE CHANGE (2020), https://policyintegrity.org/publications/detail/wisdom-of-the-experts.

[8] ILIANA PAUL ET AL., INST. FOR POL'Y INTEGRITY, THE SOCIAL COST OF GREENHOUSE GASES AND STATE POLICY: A FREQUENTLY ASKED QUESTIONS GUIDE (2017), https://policyintegrity.org/publications/detail/social-cost-of-ghgs-and-state-policy.

[9] INTERAGENCY WORKING GROUP ON THE SOCIAL COST OF GREENHOUSE GASES, TECHNICAL SUPPORT DOCUMENT: TECHNICAL UPDATE OF THE SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS (2016) [hereinafter "IWG 2016 TSD"] (citing Howard 2014, *supra* note 4).

[10] NAT'L ACADS. OF SCIS., ENG'G, AND MED., VALUING CLIMATE DAMAGES: UPDATING ESTIMATION OF THE SOCIAL COST OF CARBON DIOXIDE (2017) (citing Howard 2014, *supra* note 4; Peter Howard & Jason Schwartz, *Think Global: International Reciprocity as Justification for a Global Social Cost of Carbon*, Inst. for Pol'y Integrity Working Paper (2016), https://ssrn.com/abstract=2822513; Peter Howard & Derek Sylvan, *The Wisdom of the Economic Crowd: Calibrating Integrated Assessment Models Using Consensus*, Presented at 2016 Agric. & Applied Econ. Ass'n Ann. Meeting, Boston, MA (2016), http://ageconsearch.umn.edu/bitstream/235639/2/HowardSylvan_AAEA2016.pdf; Richard L. Revesz et al., *Global warming: Improve Economic Models of Climate Change*, 508 NATURE 173 (2014)).

[11] N.Y. Pub. Serv. Comm'n, Order Adopting a Clean Energy Standard, Case 15-E-0302 (Aug. 1, 2016), http://documents.dps.ny.gov/ public/Common/ViewDoc.aspx?DocRef Id={44C5D5B8-14C3-4F32-8399-F5487D6D8FE8} [hereinafter "NY ZECs Order"].

[12] This testimony is available at https://policyintegrity.org/documents/NJ_Legislature_SCC_Testimony.pdf.

Policy Integrity wishes to provide its expertise on the SCC to DEC as the Department develops a carbon value[13] for use by New York's agencies.

DEC's Statutory Authority and the SCC

New York's Climate Leadership and Community Protection Act (CLCPA) requires DEC to "establish a social cost of carbon for use by state agencies, expressed in terms of dollars per ton of carbon dioxide equivalent."[14] The law gives DEC the discretion to choose whether this SCC is "based on marginal greenhouse gas abatement costs" or instead on "the global economic, environmental, and social impacts of emitting a marginal ton of greenhouse gas emissions into the atmosphere."[15] Further, DEC must consider "prior or existing estimates of the social cost of carbon issued or adopted by the federal government, appropriate international bodies, or other appropriate and reputable scientific organizations."[16]

Of existing estimates, the IWG SCC numbers remain the best available marginal damage cost estimates for carbon dioxide.[17] DEC's Value of Carbon webinar presentation on July 24, 2020 demonstrates the Department's strong understanding of the SCC metric and the IWG's methodology, including the Working Group's use of discount rates, consideration of global damages in formulating its estimates, and estimates for damages from methane and nitrous oxide.[18] DEC also provided examples in the Value of Carbon webinar of other state agencies using the IWG SCC, including the New York State PSC. Given DEC's familiarity with the metric and the adoption of the IWG SCC by another state agency, it appears that the Department may intend to move forward with a value of carbon based on the IWG SCC estimates—an approach Policy Integrity supports.

Policy Integrity understands that DEC is still considering a number of elements before it issues its draft guidance. These issues include: (1) How to apply discount rates; (2) How to value other greenhouse gases; (3) How agencies can use a damage cost approach; and (4) How agencies can use other approaches for valuing carbon. This letter responds to these four considerations and concludes by addressing other issues the DEC should bear in mind when developing its guidance.

Discount Rates with the IWG SCC

DEC is exploring how to apply different discount rates to its value of carbon. A discount rate effectively demonstrates how much value is placed on future costs and benefits compared to present costs and benefits. While choosing a discount rate is necessary for both a marginal damage cost approach and a marginal abatement cost approach, this section focuses on how discount rates are applied to the IWG SCC.

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[13] Policy Integrity assumes this is a value for carbon dioxide (CO_2) emissions, which would be consistent with the IWG SCC.

[14] N.Y. PUB. LAW. § 75-0113(1), Value of Carbon.

[15] *Id.* § 75-0113(2).

[16] *Id.* § 75-0113(3).

[17] Richard L. Revesz et al. *Best Cost Estimate of Greenhouse Gases*, 357 SCI. 655 (2017), https://policyintegrity.org/documents/Science_Revesz_et_al_081718.pdf.

[18] Webinar slides are available at https://www.dec.ny.gov/docs/administration_pdf/vofcarbon072420.pdf; see slides 10–20 for DEC's presentation of the IWG SCC.

In 2010, the IWG selected three consumption discount rates—2.5-percent, 3-percent, and 5-percent[19]—to develop its range of SCC estimates. The 3-percent discount rate was intended to align with the contemporary economics literature and *Circular A-4*, a key federal guidance document on regulatory analysis.[20] The 2.5-percent discount rate was intended to "incorporate the concern that interest rates are highly uncertain over time."[21] The 2.5-percent discount rate can also act as a proxy for a declining discount rate approach.[22] Finally, the high-end discount rate of 5-percent was intended to capture "the possibility that climate damages are positively correlated with market returns."[23]

The IWG also developed an estimate using the 95th percentile of the SCC distribution corresponding to the 3-percent discount rate. This set of estimates is meant to capture high-risk low-probability events. We note that the 95th percentile does not address discount rate uncertainty per se, although this high-end estimate is also useful in sensitivity analyses.

DEC can look to other states already using the SCC for examples of the IWG's discount rates in different policy contexts. As DEC knows, the PSC currently uses the IWG SCC estimate using a 3-percent discount rate in the Benefit-Cost Analysis Handbook in its Reforming the Energy Vision proceeding,[24] including for valuing the zero-emissions attribute of nuclear power plants.[25] Other states, including Colorado and Nevada, also use the 3-percent estimate in electricity policy.[26] California uses the 3-percent estimate for calculating the climate benefits from distributed energy resources (DERs), as well as the 95th percentile high-impact estimate in sensitivity analysis.[27] Also on the West Coast, Washington State's Utilities and Transportation

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[19] IWG makes clear that the 5-percent discount rate is a consumption-based discount rate. *See* IWG, RESPONSE TO COMMENTS: SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866 (2015), https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/scc-response-to-comments-final-july-2015.pdf ("The upper value of 5 percent represents the possibility that climate damages are positively correlated with market returns, which would suggest a rate higher than the risk-free rate of 3 percent. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods.").

[20] INTERAGENCY WORKING GROUP ON THE SOCIAL COST OF CARBON, TECHNICAL SUPPORT DOCUMENT: SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866 23 (2010), https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf [hereinafter "IWG 2010 TSD"].

[21] *Id.*

[22] IWG 2010 TSD, *supra* note 20, at 23 ("The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach. Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.").

[23] *Id.*

[24] N.Y. Pub. Serv. Comm'n, Order Establishing the Benefit Cost Analysis Framework, Case 14-M-0101 (Jan. 21, 2016), http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRef Id=%7bF8C835E1-EDB5-47FF-BD78-73EB5B3B177A%7d [hereinafter "NYPSC BCA"].

[25] NY ZECs Order, *supra* note 11.

[26] Colo. Pub. Utils. Comm'n, Decision No. C17-0316, at 30, In the Matter of the Application of Public Service Company of Colorado for Approval of its 2016 Electric Resource Plan, Proceeding No. 16A-0396E (Mar. 23, 2017), https://lpdd.org/wp-content/uploads/2020/03/C17-0316_16A-0396E.pdf; Nev. Pub. Utils. Comm'n, Investigation and Rulemaking to Implement Senate Bill 65 of 2017, Docket No. 17-07020 (Aug. 5, 2018), http://pucweb1.state.nv.us/PDF/AxImages/DOCKETS_2015_THRU_PRESENT/2017-7/32153.pdf.

[27] Cal. Pub. Utils. Comm'n, Order Instituting Rulemaking to Create a Consistent Regulatory Framework for the Guidance, Planning, and Evaluation of Integrated Distributed Energy Resources, Rulemaking 14-10-003, Proposed Decision Adopting Cost-Effectiveness Analysis Framework Policies for All Distributed Energy Resources (Mar. 25, 2019), http://docs.cpuc.ca.gov/PublishedDocs/Efile/ G000/M274/K960/274960797.PDF.

Commission requires utilities to apply the SCC with a 2.5-percent discount rate in their long-term resource planning[28] and the Washington Department of Commerce's Energy Office recommends using a 2.5-percent discount rate for state government procurement.[29] This list is nonexhaustive and DEC can find additional examples of states applying the IWG SCC on our Cost of Carbon website[30] or in our April 2019 report, *Opportunities for Valuing Climate Damages in U.S. State Electricity Policy*.[31]

Policy Integrity recommends that DEC use the entire range of IWG SCC estimates in its guidance document, with a focus on the lower end of the range, from 2.5-percent to 3-percent, for its primary analysis. Generally, DEC would benefit from using a discount rate—or discount rates—backed by consensus that has also undergone public scrutiny and held up in court, like the IWG SCC discount rates.[32] Historically, evidence indicated that a 3-percent discount rate was appropriate as the estimate of the pure rate of time preference,[33] though new stated- and revealed-preference evidence implicates a lower discount rate closer to 2-percent.[34] Additionally, evidence indicates that the uncertain nature of climate impacts—both in terms of future economic growth and physical effects—supports the growing consensus that a declining discount rate, as approximated by the IWG's use of the 2.5-percent rate, should be applied to climate damages.[35] These factors generally point to DEC using a 3-percent or 2.5-percent discount rate for its primary SCC values.

DEC can also use other discount rates and SCC values in its guidance document. Specifically, DEC could include the 5-percent and the 95th percentile estimates in its guidance document, noting that 5-percent discount rate is the highest discount rate that any agency should consider for its analysis,[36] and that these two sets of values should be used in sensitivity analyses, rather than primary analyses. In addition, although lower discount rates than 2.5-percent may be justified, using one or more of the IWG's selected discount rates ensures that DEC is using an

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[28] S.B. 5116, 66th Leg., Reg. Sess. (Wash. 2019), Supporting Washington's Clean Energy Economy and Transitioning to a Clean, Affordable, and Reliable Energy Future, http://lawfilesext.leg.wa.gov/biennium/2019-20/Pdf/Bills/Senate%20Passed%20Legislature/5116-S2.PL.pdf?q=20201012071702.

[29] Off. of Energy, Wash. State Dep't of Comm., Social Cost of Carbon: Washington State Energy Office Recommendation for Standardizing the Social Cost of Carbon When Used for Public Decision-Making Processes 2 (2014), https://www.commerce.wa.gov/wp-content/uploads/2015/11/Energy-EV-Planning-Social-Cost-of-Carbon-Sept-2014.pdf.

[30] https://costofcarbon.org/.

[31] DENISE A. GRAB ET AL., INST. FOR POL'Y INTEGRITY, OPPORTUNITIES FOR VALUING CLIMATE IMPACTS IN U.S. STATE ELECTRICITY POLICY (2019), https://policyintegrity.org/publications/detail/opportunities-for-valuing-climate-impacts-in-u.s.-state-electricity-policy.

[32] Use of the IWG SCC by federal and state agencies has been upheld by multiple federal courts. *See, e.g.*, *Zero Zone*, 832 F.3d at 675 (upholding the use of the IWG SCC by the U.S. Department of Energy in the energy conservation standards for commercial refrigerators); *California v. Bernhardt*, 2020 WL 4001480 (N.D. Cal. July 15, 2020) (rejecting the use of the 'interim' SCC estimates by the Bureau of Land Management in its justification for repealing the Waste Prevention Rule); *Hudson River Sloop Clearwater, Inc. et al. v. NYSPSC, et al.* 119 N.Y.S.3d 390 (2019 N.Y. Slip Op. 51762) (affirming the New York PSC's use of the social cost of carbon in the ZECs program.).

[33] *See* OFF. OF MGMT. & BUDGET, EXEC. OFF. OF THE PRESIDENT, OMB CIRCULAR A-4, REGULATORY ANALYSIS 33–34 (2003); *see also* U.S. ENV'T PROT. AGENCY, GUIDELINES FOR PREPARING ECONOMIC ANALYSIS (2010); IWG 2010 TSD at 17-23.

[34] Kenneth Arrow et al., *Determining Benefits and Costs for Future Generations*, 341 SCIENCE 349 (2013); Kenneth J Arrow et al., *Should Governments Use a Declining Discount Rate in Project Analysis*, 8 REV. ENV'T ECON. POLICY 145 (2014); Christian Gollier & James K. Hammitt, *The Long-Run Discount Rate Controversy*, 6 ANN. REV. RES. ECON. 273 (2014); Maureen L. Cropper, Mark C. Freeman, Ben Groom, & William A. Pizer, *Declining Discount Rates*, 104 AM. ECON. REV. 538 (2014); Council of Econ. Advisers, *Discounting for Public Policy: Theory and Recent Evidence on the Merits of Updating the Discount Rate* (Issue Brief, 2017), https://obamawhitehouse.archives.gov/sites/default/files/page/files/201701_cea_discounting_issue_brief.pdf.

[35] Cropper et al. 2014, *supra* note 34; Arrow et al. 2013, *supra* note 34; Arrow et al. 2014, *supra* note 34.

[36] Howard & Sylvan 2020, *supra* note 7.

economically sound methodology.[37] A constant discount rate of 0-percent, notwithstanding its intuitive appeal, has little support in the literature,[38] and should be applied cautiously if applied at all.

Policy Integrity has written extensively on discount rates with respect to the SCC. A technical appendix we frequently submit with comments to federal agencies on the SCC is attached.

Valuing Other Greenhouse Gases

If DEC recommend that all New York State agencies use the IWG SCC estimates, it should also adopt IWG's other social cost of greenhouse gas estimates. In 2016, IWG produced marginal damage cost estimates of methane and nitrous oxide.[39] These estimates are internally consistent with the IWG SCC and are ready to apply to any policy decision that affects the emissions of these greenhouse gases. DEC can learn more about the social costs of methane and nitrous oxide in IWG's 2016 addendum.[40]

There are also a number of greenhouse gases besides carbon dioxide (CO_2), methane, and nitrous oxide that can and should be monetized. These other pollutants include fluorinated gases, like those used for refrigerants, and primary particular matter, which is also known as elemental or black carbon.[41] Currently, the easiest way to value the climate damages of these other greenhouse gases is to multiply the SCC by the global warming potential (GWP) of a given pollutant.[42]

GWP is normally calculated over 20-year and 100-year time horizons, but the CLCPA defines "carbon dioxide equivalent" as having a 20-year time horizon.[43] A 20-year time horizon sometimes yields larger values for some greenhouse gases, and the estimates corresponding to the 100-year time horizon are more in line with how scientists and economists think about climate effects, which are considered over many decades. While DEC may be statutorily required to direct agencies to use the 20-year time horizon, there is merit to using both time horizons for calculating the damages from non-CO_2 greenhouse gases, as the 100-year time horizon allows for consideration of longer-term effects. And so, DEC should direct agencies to apply both the 20- and 100-year time horizons.

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[37] *See* Moritz A. Drupp, Mark Freeman, Ben Groom & Frikk Nesje, Uni. of Oslo, *Discounting Disentangled*, *Memorandum* (Dep't of Econ., No. 20/2015, 2015); Howard & Sylvan 2020, *supra* note 7.

[38] IWG 2010 TSD at 21-22. Surveys of discount rate and economics of climate change experts (*see* Drupp et al. 2015, *supra* note 37; Howard & Sylvan 2020, *supra* note 7) find that only 5-14% of respondents support discount rates of 0% or lower. For a 0% discount rate to make empirical sense, DEC must assume a pure rate of time preference of zero and a significant probability of negative economic growth resulting from climate change. Similarly, a discount rate of 5% also has little support: only 8-10% of survey respondents support a discount rate of 5% or higher.

[39] INTERAGENCY WORKING GROUP ON THE SOCIAL COST OF GREENHOUSE GASES, ADDENDUM TO TECHNICAL SUPPORT DOCUMENT ON SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866: APPLICATION OF THE METHODOLOGY TO ESTIMATE THE SOCIAL COST OF METHANE AND THE SOCIAL COST OF NITROUS OXIDE (2016).

[40] *Id.*

[41] *See* U.S. ENV'T PROT. AGENCY, OVERVIEW OF GREENHOUSE GASES (last updated Sept. 8, 2020), https://www.epa.gov/ghgemissions/overview-greenhouse-gases. The IPCC's most recent GWP for greenhouse gases can be found in Gunnar Myhre et al., *Anthropogenic and Natural Radiative Forcing, Climate Change 2013: The Physical Science Basis. Contribution of Working Group I* in FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE at 696, Tbl. 8.6 (2013), https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf.

[42] See IWG 2010 TSD at 12 for a more in-depth explanation of how to calculate the social cost of other greenhouse gases using GWP.

[43] CLCPA § 2, N.Y. ENV'T CONSERVATION L. § 75-0101(2).

Furthermore, DEC should continue to assess its methodologies for calculating the social cost of other greenhouse gases to ensure they are in line with the best available science.

How to Apply the SCC

A marginal damage cost, such as the IWG SCC, is the monetary value of climate damages caused by each additional unit of emissions. So, the SCC is the cost to society of emitting an additional ton of CO_2 into the atmosphere. Because it captures the costs to society, using a marginal damage cost approach gives decisionmakers necessary information to set welfare maximizing policies.

As discussed above, numerous states use a damages-based approach to valuing greenhouse gas emissions. For example, the IWG SCC has been used in cost-benefit analysis tools[44] and for compensating non-emitting electricity generators.[45] Because it is a damage cost, it can also be applied to wholesale markets by regional transmission organizations/independent system operators. In particular, the New York Independent System Operator (NYISO) is currently exploring a carbon price for the wholesale market. Draft materials suggest NYISO anticipates using the IWG SCC to set this price.[46]

Though its current use by state regulators has been limited to only certain applications, such as proceedings on the value of distributed resources, zero emission credits, in resource planning documents, cost-benefit analyses, and to assess state procurement,[47] a marginal damage cost can and should be used any time DEC or another state agency needs to make a decision that affects greenhouse gas emissions.

How to Apply Other Approaches

DEC is also exploring how to apply other approaches to pricing or valuing greenhouse gas emissions, including a marginal abatement cost and market allowance prices.

Marginal abatement cost

A marginal abatement cost (MAC) is the cost of abating an additional ton of emissions. MAC is traditionally derived in two ways: first, from a policy evaluation model, and second, from a McKinsey marginal abatement curve.[48] MAC depends on a number of assumptions, including technological feasibility and existing emissions reduction policies.

DEC should note that there is not one set of global MAC estimates like there is for marginal damage cost estimates. Rather, each MAC is unique to a region or jurisdiction. It can also be estimated for different sectors of the economy when there are sector-specific emissions reduction targets in place. In New York, as there is both an economy-wide target and an electricity sector

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[44] *See, e.g.*, NYPSC BCA, *supra* note 24; CAL. AIR RES. BD., SCOPING PLAN FOR ACHIEVING CALIFORNIA'S 2030 GREENHOUSE GAS TARGET (2017), https://ww3.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf.

[45] NY ZECs Order, *supra* note 11; Ill. S.B. 2814 (Future Energy Jobs Bill), 99th Gen. Assemb., Reg. Sess. (Ill. 2016), at 135–36, http://www.ilga.gov/legislation/99/SB/ PDF/09900SB2814enr.pdf; N.J. STAT. ANN. § C.48:3-87.3.b(8) (West 2018). Though it has so far only been implemented in the context of nuclear power plants, a marginal damage cost value of carbon could also be used to compensate any other non-emitting resources, like photovoltaic panels or wind turbines, for the emissions avoided when they displace polluting generators. *See e.g.* ME. PUB. UTIL. COMM'N, MAINE DISTRIBUTED SOLAR VALUATION STUDY (2014), https://www.maine.gov/mpuc/electricity/elect_generation/documents/MainePUCVOS-FullRevisedReport_4_15_15.pdf.

[46] New York Independent System Operator, IPPTF Carbon Pricing Proposal 5 n.5 (2018).

[47] *See* GRAB ET AL., *supra* note 31, at 13–23.

[48] *See* Fabian Kesicki & Paul Ekins, *Marginal Abatement Cost Curves: A Call for Caution*, 12 CLIMATE POL'Y 219, 220 (2011).

target, the state would need to calculate two MAC estimates if it wishes to apply this methodology. If the state sets further sector-specific goals, the DEC would need a MAC for each additional sector.[49]

Unlike a marginal damage cost, MAC is not welfare maximizing because it does not represent the societal costs of emissions,[50] contrary to what other experts may assume.[51] Moreover, there is no single federal MAC estimate or set of estimates that have been legally tested, like with the IWG SCC. However, when there are legally binding emission targets in place, a MAC-based approach can be cost-minimizing and so useful for picking cost-effective policies. MAC can also be used for sensitivity analyses when marginal damage cost is used for the primary analysis: For example, using a MAC based on New York's goal of reducing emissions to 85-percent of 1990 levels by 2050 in sensitivity analysis would flag if the damage cost used was inconsistent with that emissions pathway.[52]

Allowance Price

Allowance prices, another methodology for valuing carbon emissions that DEC identified in its July 24 webinar, reflect the price of a permit to emit CO_2 in a market-trading scheme. New York participates in the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade program for the electricity sector, and so large power plants in the state[53] need allowances to emit CO_2. The cost of allowances depends on how stringent the cap is, how the market is organized, if there is a price floor or price ceiling, and other factors. Carbon allowance prices in RGGI, California, and other carbon markets, are typically well below the IWG SCC,[54] and so on their own are not sufficient for achieving the socially optimal level of emissions reductions.

Allowance prices can be complemented by other policies, including those that apply the SCC. For example, the PSC uses the SCC minus the RGGI allowance price to capture the value of climate damages not already reflected in the electricity market to compensate nuclear power plants under the ZECs program.[55]

In short, allowance prices have a useful application, but unless they reflect at least the full social cost of emissions and cover all emitters, they should not be the only value for carbon that DEC recommends.

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[49] New York has an economy-wide goal of limiting statewide emissions to 40% of 1990 levels by 2035 and 85% of 1990 levels by 2050; New York currently has specific targets for the electricity sector, but not for its other sectors that contribute to the state's greenhouse gas emissions. See New York's Sources of Emissions, https://www.dec.ny.gov/energy/99223.html.

[50] Till M. Bachman, *Considering Environmental Costs of Greenhouse Gas Emissions for Setting a CO2 tax: A Review*, 720 SCI. TOTAL ENV'T. 137524, at 5 (2020) ("Although not apt to determine an optimal emission level, the marginal costs to achieve an objective can be used if there is reason to assume that the emission target was set by policy based on a social consensus with an associated willingness to pay to achieve this target.").

[51] In a 2018 report from Synapse Energy Economics that was submitted to the PSC, Frank Ackerman, Ph.D., says: "Logically, in other words, avoiding future climate damages must be worth at least as much as the highest-priced abatement measure included in the least-cost scenario for reaching our climate targets." FRANK ACKERMAN, SYNAPSE ENERGY ECON., INC. CLIMATE COSTS AND THE "E VALUE": INCORPORATING COSTS OF CARBON EMISSIONS INTO NEW YORK'S ELECTRIC PLANNING SYSTEM 9-10 (Oct. 2, 2018), http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B7FD93D8D-F00F-460A-AC08-DB7FC5C1421C%7D.

[52] Note that because MAC is jurisdiction-specific, New York would need to do its own state-specific modeling runs.

[53] With generation capacity of 25 megawatts or greater.

[54] As of September 2, 2020, the RGGI allowance price was $6.82. RGGI, Auction Results, https://www.rggi.org/auctions/auction-results. As of August 2020, California's allowance price was $16.68. Cal. Air Res. Bd., California Cap-and-Trade Program: Summary of California-Quebec Joint Auction Settlement Prices and Results, https://ww2.arb.ca.gov/sites/default/files/2020-08/results_summary.pdf.

[55] NYPSC BCA, *supra* note 24, at 18.

Other Important Considerations

In addition to the above discussion, DEC should consider the uncertainty of both a damages-based approach and a marginal abatement cost approach, as well as how to handle SCC estimates that did not come from the Obama-era IWG.

Uncertainty

There is an inherent amount of uncertainty involved in any methodology or approach to valuing greenhouse gas emissions. This uncertainty means that decisionmakers, like DEC and other state agencies, sometimes have to make difficult choices. Using a damages-based approach with the IWG SCC estimates requires DEC to make only a few choices and allows the Department to be confident in the scientific and legal integrity of its carbon value. Using a MAC approach requires the DEC to, at the very least, (1) determine a state-specific marginal abatement curve or a state-specific policy evaluation model, (2) make decisions about discount rates, and (3) be prepared for legal challenges.

SCC Uncertainty

Critics have claimed that there is too much uncertainty to use the IWG SCC.[56] If anything, when properly accounted for, uncertainty about the full effects of climate change increases the valuation of the social cost of greenhouse gases.[57] Moreover, the IWG took the uncertain nature of climate change into account: the integrated assessment models (IAMs) used to develop the SCC show that the net effect of uncertainty about economic damages, costs of mitigation, future economic development, and many other parameters raises the SCC compared to models that use current best guesses for these inputs.[58] That being said, IAMs still underestimate the impact of uncertainty on the SCC by not accounting for fundamental features of the climate problem, such as the option value arising from the irreversibility of climate change, society's aversion to risk and other social preferences, and potential catastrophic impacts.[59] Rather than being a reason not to take action, the presence of uncertainty should counsel regulators both to use a lower discount rate that results in a higher SCC and to consider the 95th percentile SCC estimate. Most importantly, courts have rejected the argument that the IWG SCC estimates are too uncertain to use.[60] A more thorough discussion of uncertainty with respect to the IWG SCC is available in Policy Integrity's technical appendix on uncertainty, attached.

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[56] *See, e.g.*, Brief of Amicus Curiae Interstate Natural Gas Association of America in Support of Respondent at 24, *Vecinos Para el Bienestar de la Comunidad Costera et al. v. FERC*, No. 20-1045 (D.C. Cir. filed Aug. 17, 2020); Noah Kaufman et al. *A Near-Term to Net Zero Alternative to the Social Cost of Carbon for Setting Carbon Prices*, NATURE CLIMATE CHANGE (2020), https://doi.org/10.1038/s41558-020-0880-3. ("Unfortunately, the degree of uncertainty in SCC estimates spans virtually any conceivable stringency level for a CO2 pricing policy.

[57] Peterson (2006) states "Most modeling results show (as can be expected) that there is optimally more emission abatement if uncertainties in parameters or the possibility of catastrophic events are considered." S. Peterson (2006). Sonja Peterson, *Uncertainty and Economic Analysis of Climate Change: A Survey of Approaches and Findings*, 11 ENV'T MODELING & ASSESSMENT 1 (2006).

[58] Richard S. Tol, *Safe Policies in an Uncertain Climate: An Application of FUND*, 9 GLOB. ENV'T CHANGE 221 (1995); Peterson 2006, *supra* note 57; IWG 2016 TSD, *supra* note 9.

[59] Robert. S. Pindyck, *Uncertainty in Environmental Economics*. 1 REV. ENV'T ECON. & POL'Y 45 (2007); Alexander Golub et al. *Uncertainty in Integrated Assessment Models of Climate Change: Alternative Analytical Approaches*, 19 ENV'T MODELING & ASSESSMENT 99 (2014); Derek Lemoine & Ivan Rudik, *Managing Climate Change Under Uncertainty: Recursive Integrated Assessment at an Inflection Point*, 9 ANN. REV. RES. ECON. 177 (2017).

[60] *See Zero Zone* 832 F.3d 654, 675 (7th Cir. 2016), *supra* note 32 (upholding the use of the IWG SCC by the U.S. Department of Energy in the energy conservation standards for commercial refrigerators); *California* 2020 WL 4001480, at *33 (N.D. Cal. July 15, 2020), *supra* note 32 (rejecting BLM's use of the 'interim' social cost estimates and noting that the Executive

MAC Uncertainty

Using MAC instead of the SCC requires DEC to make a number of decisions and assumptions. First, DEC would need to either develop a New York-specific policy evaluation model, showing what level of carbon price would be needed to reach the intended emissions targets, or a marginal abatement curve, showing every abatement project that would contribute to emissions reductions.

Second, MAC has two main sources of uncertainty. First, MAC becomes more uncertain as the expected emissions reduction pathways become more ambitious.[61] More ambitious targets require society to move farther from existing technologies and arrangements towards others that exist only in theory. Second, MAC curves expand the potential range of appropriate discount rates, increasing uncertainty, as they raise complicated issues of when private versus social and consumption versus capital rates are appropriate.[62] This is particularly true when applying ambitious mitigation pathways that negate the intergenerational aspect of climate change.[63]

Finally, there are also possible legal challenges to the application of MAC in setting policies. While the IWG SCC has faced a number of legal challenges at the state and federal levels, it has been held up by several courts.[64] However, the use of MAC for greenhouse gas emissions by a regulatory body has never undergone legal scrutiny, unlike the IWG SCC, so DEC and other New York agencies would not be able to rely on legal precedent to support their use of MAC.

Order that disbanded the IWG "has no legal impact on the consensus that IWG's estimates constitute the best available science about monetizing the impacts of greenhouse gas emissions").

[61] *See* Onno Kuik et al., *Marginal Abatement Costs of Greenhouse Gas Emissions: A Meta-Analysis*, 37 ENERGY POL'Y 1395, 1400 (showing in Fig. 2 that "MAC is strongly increasing in the stringency of the long-run target and that the uncertainty of the prediction strongly increases when the target becomes stricter"); *see also* Leon Clarke et al., Intergovernmental Panel on Climate Change, *Assessing Transformation Pathways. Climate Change 2014: Mitigation of Climate Change,* FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 451 (2014) ("As expected, carbon prices and mitigation costs increase with the amount of mitigation. Since different models have different capabilities for deep emissions reductions, the intermodal spread in carbon price and cost estimates increases as well. In other words, scenarios indicate greater consensus regarding the nature of mitigation costs at higher-concentration levels than those at lower levels. This increase in variation reflects the challenge associated with modelling energy and other human systems that are dramatically different than those of today."); DALLAS BURTRAW ET AL., RES. FOR THE FUTURE, QUANTITIES WITH PRICES 5 (2018) ("The costs of meeting [declining emissions] caps are highly uncertain, particularly further into the future as policy goals become more ambitious.").

[62] *See* Kesicki & Ekins 2011, *supra* note 48, at 224-25 ("[W]ith the current discount methodology the cost numbers tell policy makers what might be preferential from a least-cost point of view of society as a whole. However, not all decarbonization investment decisions are made from this perspective. The private sector will make decisions within the context of its own cost calculations, based on a different discount rate, with a different implicit MAC curve. Hence, the social MAC curve may give some guidance to the reader as to what may be desirable from the perspective of maximizing social welfare, but will not tell the reader what the market will do.").

[63] *See, e.g.*, Noah Kaufman et al. 2020, *supra* note 56. In this case, because climate damages are a public cost but the investments necessary to reduce greenhouse gases are largely private, DEC would need to use its judgement as to when the application of private or social discount rates is appropriate. Additionally, as the burden of abatement would fall mostly on private owners of capital and the intergenerational impacts on greater society would be greatly reduced by ambitious climate targets, the application of private and social capital discount rates, like 7%, are potentially more appropriate instead of the consumption discount rates favored by theory in the social cost of carbon context.

[64] *See, e.g., Zero Zone,* 832 F.3d, *supra* note 32, at 675 (upholding the use of the IWG SCC by the U.S. Department of Energy in the energy conservation standards for commercial refrigerators); *California*, 2020 WL 4001480 (N.D. Cal. July 15, 2020), *supra* note 32 (rejecting the use of the 'interim' SCC estimates by the Bureau of Land Management in its justification for repealing the Waste Prevention Rule); *Hudson River Sloop Clearwater*, 119 N.Y.S.3d 390 (2019 N.Y. Slip Op. 51762), *supra* note 32 (affirming the New York PSC's use of the social cost of carbon in the ZECs program.).

Other social cost of carbon estimates

DEC may be aware that there are other SCC estimates in use or in development. This section briefly touches on two: The Trump administration's 'interim' estimates and potential new estimates that update the IWG's methodology and inputs.

So-called 'interim' estimates

A number of federal agencies have used SCC estimates based on domestic-only climate damages, an approach that is flawed for a number of reasons.[65] First, no methodology exists to accurately value U.S.-specific climate damages, let alone a state-specific ones.[66] Second, climate impacts outside of the nation's borders impose costs on the United States, so it is logical and in the best interest of the United States, and individual states, to use global damage estimates.[67] Third, using global damages encourages reciprocity with respect to the climate mitigation efforts of other countries and states; such cooperation is necessary to take meaningful action to reduce emissions.[68] Notably, every U.S. state that has adopted a SCC to date has used a global estimate. Therefore, DEC should use the IWG SCC estimates that focus on global damages, rather than attempting to adopt or calculate a domestic- or state-only SCC.

Updates to the IWG estimates

DEC should note that the IWG estimates may be improved upon in the near future, though probably not before the December 31, 2020 statutory deadline for promulgation of a social cost of carbon for use by state agencies.[69] Any new estimates DEC considers should be unbiased and based on the best available science. Two nonprofits, Resources for the Future (RFF)[70] and Climate Impact Lab,[71] are developing updates to the IWG SCC, but these estimates have not yet been released, nor will they be ready for use in official decisionmaking until they have undergone thorough examination. For example, even though RFF is making updates consistent with National Academies Sciences' guidance, its new SCC estimates would need to face public comment and scrutiny to ensure that they are, in fact, unbiased and based on the best available science. RFF's estimates may also need to withstand legal challenges in the courts. If DEC is interested in undertaking its own effort to update the IWG estimates, it should consider pooling resources with other interested states, and keep in mind that its methodology will need to undergo review before it can be applied.

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[65] *See California* 2020 WL 4001480 (N.D. Cal. July 15, 2020) (rejecting the use of the 'interim' SCC estimates by the Bureau of Land Management in its justification for repealing the Waste Prevention Rule), *supra* note 32.

[66] *See* Inst. for Pol'y Integrity, Comments to the Department of Energy on Monetizing Emissions Reductions in the Technical Support Document for the Room Air Conditioners Request for Information (Docket No. EERE-2014-BT-STD-0059) 12-16 (Sept. 8, 2020), https://policyintegrity.org/documents/Joint_SCC_comments_DOE_Rm_AC_RFI_TSD_2020.09.08.pdf.

[67] *See id.* at 6-10.

[68] *See id.* at 8-9; *see also* Howard & Schwartz 2017, *supra* note 5; *see also* U.S. COMMODITY FUTURES TRADING COMM'N, CLIMATE-RELATED MKT. RISK SUBCOMM., MANAGING CLIMATE RISK IN THE U.S. FINANCIAL SYSTEM (2020) (noting throughout the interconnectedness of the global financial system and the importance of cooperation between the United States and other countries).

[69] *See* CLCPA § 2, N.Y. ENV'T CONSERVATION L. § 75-0113(1) (setting deadline at one year after CLCPA's entry into effect).

[70] More information is available at https://www.rff.org/social-cost-carbon-initiative/.

[71] More information is available at https://www.impactlab.org/research-area/social-cost/.

Attachments:

Appendix A: List of Policy Integrity Comments to New York State Regulators

Technical Appendix – Uncertainty

Technical Appendix – Discounting

Appendix A: List of Policy Integrity Comments to New York State Regulators

Comments in response to Brattle Group analyses presented at July 10, 2020 technical conference on resource adequacy (Aug. 21, 2020), https://policyintegrity.org/projects/update/comments-to-the-new-york-psc-on-resource-adequacy;

Comments on Resource Adequacy (Nov. 8, 2019), https://policyintegrity.org/projects/update/comments-to-the-new-york-public-service-commission-on-resource-adequacy;

Comments on New York State Energy Storage Deployment Program (Sept. 10, 2018), https://policyintegrity.org/projects/update/comments-on-new-york-state-energy-storage-roadmap;

Comments on New York State Public Service Commission's Notice Soliciting Comments in the Matter of Offshore Wind Energy, Matter No. 18-E-0071 (Jun. 4, 2018), https://policyintegrity.org/projects/update/comments-to-new-york-on-offshore-wind-program;

Comments on Rate Design Successor to Net Energy Metering for Mass Market Customers (May 29, 2018), https://policyintegrity.org/projects/update/comments-to-new-york-on-electricity-rate-design;

Coalition for Sustainable Distributed Clean Energy Comments on Rate Design Successor to Net Energy Metering for Mass Market Customers (May 29, 2018), https://policyintegrity.org/projects/update/comments-to-new-york-on-electricity-rate-design;

Comments on Staff Report Regarding Retention of Existing Baseline Resources under Tier 2 of the Renewable Energy Standard Program (Jan. 8, 2018), https://policyintegrity.org/projects/update/comments-to-new-york-state-on-clean-energy-standards-for-existing-generator;

Comments on the Staff Scope of Study to Examine Bill Impacts of a Range of Mass Market Rate Reform Scenarios (Dec. 11, 2017), https://policyintegrity.org/projects/update/comments-on-scope-of-bill-impact-study-to-new-york;

Comments on the Notice on Process, Soliciting Proposals and Comments, and Announcing Technical Conference (Nov. 30, 2017), https://policyintegrity.org/projects/update/comments-on-carbon-pricing-in-wholesale-electricity-markets-to-new-york

Comments on Matter No. 17-01821 In the Matter of Carbon Pricing in New York Wholesale Markets NYISO/DPS Integrating Public Policy Task Force (Nov. 10, 2017), https://policyintegrity.org/documents/2017-11-10_Policy_Integrity_Comments_-_NY_IPPTF_Work_Plan.pdf

Joint Comments with Environmental Defense Fund on Case 15-E-0751 – In the Matter of the Value of Distributed Energy Resources and Options Related to Establishing an Interim

Methodology (Dec. 5, 2016), https://policyintegrity.org/projects/update/comments-on-distributed-energy-valuation-in-new-york

Comments on New York State Department of Public, Petitions for Rehearing on Clean Energy Standard (Oct. 31, 2016), https://policyintegrity.org/documents/Policy_Integrity_CES_Petition_Comments.pdf

Reply Comments on the New York State Department of Public Service, Benefit Cost Analysis Handbooks in the Reforming Energy Vision Proceeding (Sept. 26, 2016), https://policyintegrity.org/projects/update/comments-on-new-york-state-benefit-cost-analysis-handbooks

Comments on Staff's Responsive Proposal for Preserving Zero-Emissions Attributes, Docket No. 299 (July 8, 2016) (Jul. 22, 2016), https://policyintegrity.org/documents/Policy_Integrity_Comments_on_Staffs_Responsive_Proposal_for_Preserving_Zero-Emissions_Attributes.pdf

Comments on New York State Department of Public Service, Staff White Paper on Clean Energy Standard, Docket No. 81 (January 25, 2016) (Apr. 22, 2016), https://policyintegrity.org/documents/Comments_on_Clean_Energy_Standard_White_Paper.pdf

Joint Comments on Case 15-E-0751 – In the Matter of the Value of Distributed Energy Resources and Options Related to Establishing an Interim Methodology (Apr. 18, 2016), https://policyintegrity.org/projects/update/comments-on-net-metering-and-distributed-energy-valuation-in-new-york

Comments on New York State Department of Public Service, Staff White Paper on Ratemaking and Utility Business Models, Docket No. 416 (July 28, 2015) (Oct. 26, 2015), https://policyintegrity.org/projects/update/comments-on-new-york-state-energy-policy

Comments on New York State Department of Public Service, Staff White Paper on Benefit-Cost Analysis in the Reforming Energy Vision Proceeding, Docket No. 392 (July 1, 2015) (Aug. 21, 2015), https://policyintegrity.org/documents/REV_Comments_Aug2015.pdf

Joint Comments with the Guarini Center on Environmental and Land Use Law on the Con Edison Storm Hardening and Resilience Report (Jan. 10, 2014), https://policyintegrity.org/projects/update/comments-on-con-edison-storm-hardening-and-resilience-collaborative-report

Technical Appendix: Uncertainty

Contrary to the arguments made by many opposed to strong federal climate action, uncertainty about the full effects of climate change *raises* the social cost of greenhouse gases and warrants *more* stringent climate policy.[1] Integrated assessment models (IAMs) currently used to calculate the social cost of carbon (SCC) show that the net effect of uncertainty about economic damage resulting from climate change, costs of mitigation, future economic development, and many other parameters raises the SCC compared to the case where models simply use our current best guesses of these parameters.[2] Even so, IAMs still underestimate the impact of uncertainty on the SCC by not accounting for a host of fundamental features of the climate problem: the irreversibility of climate change, society's aversion to risk and other social preferences, option value, and many catastrophic impacts.[3] Rather than being a reason not to take action, uncertainty increases the SCC and should lead to more stringent policy to address climate change.[4]

Types of Uncertainty in the IAMs

IAMs incorporate two types of uncertainty: parametric uncertainty and stochastic uncertainty. Parametric uncertainty covers uncertainty in model design and inputs, including the selected parameters, correct functional forms, appropriate probability distribution functions, and model structure. With learning, these uncertainties should decline over time as more information becomes available.[5] Stochastic uncertainty is persistent randomness in the economic-climate system, including various environmental phenomena such as volcanic eruptions and sun spots.[6] Uncertainties are present in each component of the IAMs: socio-economic scenarios, the simple

[1] Peterson (2006) states "Most modeling results show (as can be expected) that there is optimally more emission abatement if uncertainties in parameters or the possibility of catastrophic events are considered." Peterson, S. (2006). Uncertainty and economic analysis of climate change: A survey of approaches and findings. *Environmental Modeling & Assessment*, *11*(1), 1-17.

[2] Tol, R. S. (1999). Safe policies in an uncertain climate: an application of FUND. *Global Environmental Change*, *9*(3), 221-232; Peterson, S. (2006). Uncertainty and economic analysis of climate change: A survey of approaches and findings. *Environmental Modeling & Assessment*, *11*(1), 1-17; Interagency Working Group on Social Cost of Carbon, Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12,866 (2016).

[3] Pindyck, R. S. (2007). Uncertainty in environmental economics. *Review of environmental economics and policy*, *1*(1), 45-65; Golub, A., Narita, D., & Schmidt, M. G. (2014). Uncertainty in integrated assessment models of climate change: Alternative analytical approaches. *Environmental Modeling & Assessment*, *19*(2), 99-109; Lemoine, D., & Rudik, I. (2017). Managing Climate Change Under Uncertainty: Recursive Integrated Assessment at an Inflection Point. *Annual Review of Resource Economics* 9:18.1-18.26.

[4] *See* cites *supra* note 3.

[5] Learning comes in multiple forms: passive learning of anticipated information that arrives exogenous to the emission policy (such as academic research), active learning of information that directly stems from the choice of the GHG emission level (via the policy process), and learning of unanticipated information (Kann and Weyant, 2000; Lemoine and Rudik, 2017).

[6] Kann, A., & Weyant, J. P. (2000). Approaches for performing uncertainty analysis in large-scale energy/economic policy models. *Environmental Modeling & Assessment*, *5*(1), 29-46; Peterson (2006), *supra* note 1; Golub et al. *supra* note 3.

A potential third type of uncertainty arises due to ethical or value judgements: normative uncertainty. Peterson (2006) *supra* note 1; Heal, G., & Millner, A. (2014). Reflections: Uncertainty and decision making in climate change economics. *Review of Environmental Economics and Policy*, *8*(1), 120-137. For example, there is some normative debate over the appropriate consumption discount rate to apply in climate economics, though widespread consensus exists that using the social opportunity cost of capital is inappropriate (see earlier discussion). Preference uncertainty should be modeled as a declining discount rate over time (see earlier discussion), not using uncertain parameters. Kann & Weyant, *supra* note 6.

climate model, the damage and abatement cost functions, and the social welfare function (including the discount rate).[7]

When modeling climate change uncertainty, scientists and economists have long emphasized the importance of accounting for the potential of catastrophic climate change.[8] Catastrophic outcomes combine several overlapping concepts including unlucky states of the world (i.e., bad draws), deep uncertainty, and climate tipping points and elements.[9] Traditionally, IAM developers address uncertainty by specifying probability distributions over various climate and economic parameters. This type of uncertainty implies the possibility of an especially bad draw if multiple uncertain parameters turn out to be lower than we expect, causing actual climate damages to greatly exceed expected damages.

Our understanding of the climate and economic systems is also affected by so-called "deep uncertainty," which can be thought of as uncertainty over the true probability distributions for specific climate and economic parameters.[10] The mean and variance of many uncertain climate phenomena are unknown due to lack of data, resulting in "fat-tailed distributions"—i.e., the tail of the distributions decline to zero slower than the normal distribution. Fat-tailed distributions result when the best guess of the distribution is derived under learning.[11] Given the general opinion that bad surprises are likely to outweigh good surprises in the case of climate change,[12] modelers capture deep uncertainty by selecting probability distributions with a fat upper tail which reflects the greater likelihood of extreme events.[13] The possibility of fat tails increases the likelihood of a "very" bad draw with high economic costs, and can result in a very high (and potentially infinite) expected cost of climate change (a phenomenon known as the dismal theory).[14]

Climate tipping elements are environmental thresholds where a small change in climate forcing can lead to large, non-linear shifts in the future state of the climate (over short and long periods

[7] Peterson (2006), *supra* note 1; Pindyck (2007), *supra* note 3; Heal & Millner, *supra* note 6.

[8] Nordhaus, W. D. (2008). A question of balance: Weighing the options on global warming policies. Yale University Press; Kopp, R. E., Shwom, R. L., Wagner, G., & Yuan, J. (2016). Tipping elements and climate–economic shocks: Pathways toward integrated assessment. *Earth's Future*, *4*(8), 346-372.

[9] Kopp et al. (2016), *supra* note 8.

[10] *Id.*

[11] Nordhaus, W. D. (2009). An Analysis of the Dismal Theorem (No. 1686). Cowles Foundation Discussion Paper; Weitzman, M. L. (2011). Fat-tailed uncertainty in the economics of catastrophic climate change. Review of Environmental Economics and Policy, 5(2), 275-292; Pindyck, R. S. (2011). Fat tails, thin tails, and climate change policy. *Review of Environmental Economics and Policy*, *5*(2), 258-274.

[12] Mastrandrea, M. D. (2009). Calculating the benefits of climate policy: examining the assumptions of integrated assessment models. Pew Center on Global Climate Change Working Paper; Tol, R. S. (2012). On the uncertainty about the total economic impact of climate change. *Environmental and Resource Economics*, *53*(1), 97-116.

[13] Weitzman (2011), *supra* note 11, makes clear that "deep structural uncertainty about the unknown unknowns of what might go very wrong is coupled with essentially unlimited downside liability on possible planetary damages. This is a recipe for producing what are called 'fat tails' in the extreme of critical probability distributions."

[14] Weitzman, M. L. (2009). On modeling and interpreting the economics of catastrophic climate change. The Review of Economics and Statistics, 91(1), 1-19; Nordhaus (2009), *supra* note 11; Weitzman (2011), *supra* note 11.

of time) through positive feedback (i.e., snowball) effects.[15] Tipping points refer to economically relevant thresholds after which change occurs rapidly (i.e., Gladwellian tipping points), such that opportunities for adaptation and intervention are limited.[16] Tipping point examples include the reorganization of the Atlantic meridional overturning circulation (AMOC) and a shift to a more persistent El Niño regime in the Pacific Ocean.[17] Social tipping points—including climate-induced migration and conflict—also exist. These various tipping points interact, such that triggering one tipping point may affect the probabilities of triggering other tipping points.[18] There is some overlap between tipping point events and fat tails in that the probability distributions for how likely, how quick, and how damaging tipping points will be are unknown.[19] Accounting fully for these most pressing, and potentially most dramatic, uncertainties in the climate-economic system matter because humans are risk averse and tipping points—like many other aspects of climate change—are, by definition, irreversible

How IAMs and the IWG Account for Uncertainty

Currently, IAMs (including all of those used by the IWG) capture uncertainty in two ways: deterministically and through uncertainty propagation. For the deterministic method, the modeler assumes away uncertainty (and thus the possibility of bad draws and fat tails) by setting parameters equal to their most likely (median) value. Using these values, the modeler calculates the median SCC value. Typically, the modeler conducts sensitivity analysis over key parameters—one at a time or jointly—to determine the robustness of the modeling results. This is the approach employed by Nordhaus in the preferred specification of the DICE model[20] used by the IWG.

Uncertainty propagation is most commonly carried out using Monte Carlo simulation. In these simulations, the modeler randomly draws parameter values from each of the model's probability distributions, calculates the SCC for the draw, and then repeats this exercise thousands of times to calculate a mean social cost of carbon.[21] Tol, Anthoff, and Hope employ this technique in FUND and PAGE—as did the IWG (2010, 2013, and 2016)—by specifying probability

[15] Tipping elements are characterized by: (1) deep uncertainty, (2) absence from climate models, (3) larger resulting changes relative to the initial change crossing the relevant threshold, and (4) irreversibility. Kopp et al. (2016), *supra* note 8.

[16] *Id.*

[17] *Id.*; Kriegler, E., Hall, J. W., Held, H., Dawson, R., & Schellnhuber, H. J. (2009). Imprecise probability assessment of tipping points in the climate system. *Proceedings of the national Academy of Sciences*, *106*(13), 5041-5046; Diaz, D., & Keller, K. (2016). A potential disintegration of the West Antarctic Ice Sheet: Implications for economic analyses of climate policy. *The American Economic Review*, *106*(5), 607-611. See Table 1 of Kopp et al. (2016) *supra* note 8, for a full list of known tipping elements and points.

[18] Kriegler et al. (2009), *supra* note 17; Cai, Y., Lenton, T. M., & Lontzek, T. S. (2016). Risk of multiple interacting tipping points should encourage rapid CO2 emission reduction; Kopp et al. (2016) *supra* note 8.

[19] Peter Howard, *Omitted Damages: What's Missing from the Social Cost of Carbon* 5 (Cost of Carbon Project Report, 2014), http://costofcarbon.org/; Kopp et al. (2016) *supra* note 8.

[20] Nordhaus, W. & Sztorc, P. (2013). DICE 2013: Introduction & User's Manual. Retrieved from Yale University, Department of Economics website: http://www.econ.yale.edu/~nordhaus/homepage/documents/Dicemanualfull

[21] In alternative calculation method, the modeler "performs optimization of polices for a large number of possible parameter combinations individually and estimates their probability weighted sum." Golub et al. *supra* note 3. In more recent DICE-2016, Nordhaus conducts a three parameter analysis using this method to determine a SCC confidence interval. Given that PAGE and FUND model hundred(s) of uncertainty parameters, this methodology appears limited in the number of uncertain variables that can be easily specified.

distributions for the climate and economic parameters in the models. These models are especially helpful for assessing the net effect of different parametric and stochastic uncertainties. For instance, both the costs of mitigation and the damage from climate change are uncertain. Higher costs would warrant less stringent climate policies, while higher damages lead to more stringent policy, so theoretically, the effect of these two factors on climate policy could be ambiguous. Uncertainty propagation in an IAM calibrated to empirically motivated distributions, however, shows that climate damage uncertainty outweighs the effect of cost uncertainty, leading to a stricter policy when uncertainty is taken into account than when it is ignored.[22] This can be seen in the resulting right-skewed distribution of the SCC (see Figure 1 in IWG (2016)) where the mean (Monte Carlo) SCC value clearly exceeds the median (deterministic) SCC value.

The IWG was rigorous in addressing uncertainty. First, it conducted Monte Carlo simulations over the above IAMs specifying different possible outcomes for climate sensitivity (represented by a right skewed, fat tailed distribution to capture the potential of higher than expected warming). It also used scenario analysis: five different emissions growth scenarios and three discount rates. Second, the IWG (2016) reported the various moments and percentiles—including the 95th percentile—of the resulting SCC estimates. Third, the IWG put in place an updating process, e.g., the 2013 and 2016 revisions, which updates the models as new information becomes available.[23] As such, the IWG used the various tools that economists have developed over time to address the uncertainty inherent in estimating the economic cost of pollution: reporting various measures of uncertainty, using Monte Carlo simulations, and updating estimates as evolving research advances our knowledge of climate change. Even so, the IWG underestimates the SCC by failing to capture key features of the climate problem.

Current IAMs Underestimate the SCC by Failing to Sufficiently Model Uncertainty

Given the current treatment of uncertainty by the IWG (2016) and the three IAMs that they employ, the IWG (2016) estimates represent an underestimate of the SCC. DICE clearly underestimates the true value of the SCC by effectively eliminating the possibility of bad draws and fat tails through a deterministic model that relies on the median SCC value. Even with their calculation of the mean SCC, the FUND and PAGE also underestimate the metric's true value by ignoring key features of the climate-economic problem. Properly addressing the limitations of these models' treatment of uncertainty would further increase the SCC.

First, current IAMs insufficiently model catastrophic impacts. DICE fails to model both the possibility of bad draws and fat tails by applying the deterministic approach. Alternatively, FUND and PAGE ignore deep uncertainty by relying predominately on the thin-tailed triangular and gamma distributions.[24] The IWG (2010) only partially addresses this oversight by replacing

[22] Tol (1999), *supra* note 2, in characterizing the FUND model, states, "Uncertainties about climate change impacts are more serious than uncertainties about emission reduction costs, so that welfare-maximizing policies are stricter under uncertainty than under certainty."

[23] IWG (2010).

[24] Howard (2014), *supra* note 19. While both FUND and PAGE employ thin tailed distributions, the resulting distribution of the SCC is not always thin-tailed. In PAGE09, the ECS parameter is endogenous, such that the distribution of the ECS has a long tail following the IPCC (2007). *See* Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., & Miller, H. L. (2007). Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. *Cambridge, UK and New York: Cambridge University Press, 996p*. Similarly, while Anthoff and Tol do not explicitly utilize fat-tail distributions, the

the ECS parameter in DICE, FUND, and PAGE with a fat-tailed, right-skewed distribution calibrated to the IPCC's assumptions (2007), even though many other economic and climate phenomenon in IAMs are likely characterized by fat tails, including climate damages from high temperature levels, positive climate feedback effects, and tipping points.[25] Recent work in stochastic dynamic programming tends to better integrate fat tails – particularly with respect to tipping points (see below) – and address additional aversion to this type of uncertainty (also known as ambiguity aversion); doing so can further increase the SCC under uncertainty.[26]

In contrast to their approach to fat tails, the IAMs used by the IWG (2010; 2013; 2016) sometimes address climate tipping points, though they do not apply state-of-the-art methods for doing so. In early versions of DICE (DICE-2010 and earlier), Nordhaus implicitly attributes larger portions of the SCC to tipping points by including certainty equivalent damages of catastrophic events - representing two-thirds to three-quarter of damages in DICE – calibrated to an earlier Nordhaus (1994) survey of experts.[27] In PAGE09, Hope also explicitly models climate tipping points as a singular, discrete event (of a 5% to 25% loss in GDP) that has a probability (which grows as temperature increases) of occurring in each time period.[28] Though not in the preferred versions of the IAMs employed by the IWG, some research also integrates specific tipping points into these IAMs finding even higher SCC estimates.[29] Despite the obvious methodological basis for addressing tipping points, the latest versions of DICE[30] and FUND exclude tipping points in their preferred specifications. Research shows that if these models were to correctly account for the full range of climate impacts—including tipping points—the resulting SCC estimates would increase.[31]

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distribution of net present welfare from a Monte Carlos simulation is fat tailed. Anthoff, D., & Tol, R. S. (2014). The Climate Framework for Uncertainty, Negotiation and Distribution (FUND): Technical description, Version 3.8. Available at www.fund-model.org. Explicitly modeling parameter distributions as fat tailed may further increase the SCC.

[25] Weitzman (2011), *supra* note 11; Kopp et al. (2016) *supra* note 8.

[26] Lemoine, D., & Traeger, C. P. (2016a). Ambiguous tipping points. *Journal of Economic Behavior & Organization*, *132*, 5-18; Lemoine & Rudik (2017), *supra* note 3. IAM modelers currently assume that society is equally averse to known unknown and known unknowns. Lemoine & Traeger, *supra* note 26.

[27] Nordhaus, W. D., & Boyer, J. (2000). Warning the World: Economic Models of Global Warming. MIT Press (MA); Nordhaus, W. D. (2008). A question of balance: Weighing the options on global warming policies. Yale University Press; Howard (2014), *supra* note 19; Kopp et al. (2016) *supra* note 8.

[28] Hope (2006) also calibrated a discontinuous damage function in PAGE-99 used by IWG (2010). Howard (2014), *supra* note 19.

[29] Kopp et al. (2016) *supra* note 8.

[30] For DICE-2013 and DICE-2016, Nordhaus calibrates the DICE damage function using a meta-analysis based on estimates that mostly exclude tipping point damages. Howard, P. H., & Sterner, T. (2016). Few and Not So Far Between: A Meta-analysis of Climate Damage Estimates. *Environmental and Resource Economics*, 1-29.

[31] Using FUND, Link and Tol (2010) find that a collapse of the AMOC would decrease GDP (and thus increase the SCC) by a small amount. Earlier modeling of this collapse in DICE find a more significance increase. Keller, K., Tan, K., Morel, F. M., & Bradford, D. F. (2000). Preserving the ocean circulation: implications for climate policy. *Climatic Change*, *47*, 17-43; Mastrandrea, M. D., & Schneider, S. H. (2001). Integrated assessment of abrupt climatic changes. *Climate Policy*, *1*(4), 433-449; Keller, K., Bolker, B. M., & Bradford, D. F. (2004). Uncertain climate thresholds and optimal economic growth. *Journal of Environmental Economics and management*, *48*(1), 723-741. With respect to thawing of the permafrost, Hope and Schaefer (2016), Economic impacts of carbon dioxide and methane released from thawing permafrost. *Nature Climate Change*, *6*(1), 56-59, and Gonzalez-Eguino and Neumann (2016), González-Eguino, M., & Neumann, M. B. (2016). Significant implications of permafrost thawing for climate change control. *Climatic Change*, *136*(2), 381-388, find increases in damages (and thus an increase in the SCC) when integrating this tipping element into the PAGE09 and DICE-2013R, respectively. Looking at the collapse of the West Antarctic Ice sheet, Nicholls et al. (2008) find a potential for significant increases in costs (and thus the

The IWG approach also fails to include a risk premium—that is, the amount of money society would require in order to accept the uncertainty (i.e., variance) over the magnitude of warming and the resulting damages from climate change relative to mean damages (IWG, 2010; IWG, 2015)). The mean of a distribution, which is a measure of a distribution's central tendency, represents only one descriptor or "moment" of a distribution's shape. Each IAM parameter and the resulting SCC distributions have differing levels of variance (i.e., spread around the mean), skewness (i.e., a measure of asymmetry), and kurtosis (which, like skewness, is another descriptor of a distribution's tail) as well as means.[32] It is generally understood that people are risk averse in that they prefer input parameter distributions and (the resulting) SCC distributions with lower variances, holding the mean constant.[33] While the IWG assumes a risk-neutral central planner by using a constant discount rate (setting the risk premium to zero), this assumption does not correspond with empirical evidence,[34] current IAM assumptions,[35] the NAS (2017) recommendations, nor with the IWG's own discussion (2010) of the possible values of the elasticity of the marginal utility of consumption. Evidence from behavioral experiments indicate that people and society are also averse to other attributes of parameter distributions – specifically to the thickness of the tails of distributions – leading to an additional ambiguity premium (Heal and Millner, 2014).[36] Designing IAMs to properly account for the risk and ambiguity premiums from uncertain climate damages would increase the resulting SCC values they generate.

Even under the IWG's current assumption of risk neutrality, the mean SCC from uncertainty propagation excludes the (real) option value of preventing marginal CO_2 emissions.[37] Option

SCC) in FUND. Nicholls, R. J., Tol, R. S., & Vafeidis, A. T. (2008). Global estimates of the impact of a collapse of the West Antarctic ice sheet: an application of FUND. *Climatic Change*, *91*(1), 171-191. Ceronsky et al. (2011) model three tipping points (collapse of the Atlantic Ocean Meridional Overturning Circulation, large scale dissociation of oceanic methane hydrates; and a high equilibrium climate sensitivity parameter), and finds a large increase in the SCC in some cases. Ceronsky, M., Anthoff, D., Hepburn, C., & Tol, R. S. (2011). *Checking the price tag on catastrophe: The social cost of carbon under non-linear climate response* (No. 392). ESRI working paper.

[32] Golub, A., & Brody, M. (2017). Uncertainty, climate change, and irreversible environmental effects: application of real options to environmental benefit-cost analysis. *Journal of Environmental Studies and Sciences*, 1-8; see Figure 1 in IWG (2016).

[33] In other words, society prefers a narrow distribution of climate damages around mean level of damages X to a wider distribution of damages also centered on the same mean of X because they avoid the potential for very high damages even at the cost of eliminating the chance of very low damages.

[34] IWG 2010, *supra* note 23; Cai et al., 2016, *supra* note 18, at 521.

[35] The developers of each of the three IAMs used by the IWG (2010; 2013; 2016) assume a risk aversion society. Nordhaus and Sztorc (2013), *supra* note 20; Anthoff, D., & Tol, R. S. (2010). The Climate Framework for Uncertainty, Negotiation and Distribution (FUND): Technical description, Version 3.5. Available at www.fund-model.org; Anthoff, D., & Tol, R. S. (2014). The Climate Framework for Uncertainty, Negotiation and Distribution (FUND): Technical description, Version 3.8. Available at www.fund-model.org; Hope, C. (2013). Critical issues for the calculation of the social cost of CO2: why the estimates from PAGE09 are higher than those from PAGE2002. *Climatic Change*, *117*(3), 531-543.

[36] According to Heal and Millner (2014), *supra*, there is an ongoing debate of whether ambiguity aversion is rational or a behavioral mistake. Given the strong possibility that this debate is unlikely to be resolved, the authors recommend exploring both assumptions.

[37] Arrow, K. J., & Fisher, A. C. (1974). Environmental preservation, uncertainty, and irreversibility. *The Quarterly Journal of Economics*, 312-319; Dixit, A.K., Pindyck, R.S., 1994. *Investment Under Uncertainty*. Princeton University Press, Princeton, NJ; Traeger, C. P. (2014). On option values in environmental and resource economics. *Resource and Energy Economics*, *37*, 242-252.

In the discrete emission case, there are two overlapping types of option value: real option value and quasi-option value. Real option value is the full value of future flexibility of maintaining the option to mitigate, and mathematically equals the maximal value that can be derived from the option to [emit] now or later (incorporating learning) less the maximal value that can be value reflects the value of future flexibility due to uncertainty and irreversibility; in this case, the irreversibility of CO_2 emissions due to their long life in the atmosphere.[38] If society exercises the option of emitting an additional unit of CO_2 emissions today, "we will lose future flexibility that the [mitigation] option gave" leading to possible "regret and…a desire to 'undo'" the additional emission because it "constrains future behavior."[39] Given that the SCC is calculated on the Business as Usual (BAU) emission pathway, option value will undoubtedly be positive for an incremental emission because society will regret this emission in most possible futures.

Though sometimes the social cost of carbon and a carbon tax are thought of as interchangeable ways to value climate damages, agencies should be careful to distinguish two categories of the literature. The first is the economic literature that calculates the optimal carbon tax in a scenario where the world has shifted to an optimal emissions pathway. The second is literature that assesses the social cost of carbon on the business-as-usual (BAU) emissions pathway; the world is currently on the BAU pathway, since optimal climate policies have not been implemented. There are currently no numerical estimates of the risk premium and option value associated with an incremental emission on the BAU emissions path. Although there are stochastic dynamic optimization models that implicitly account for these two values, they analyze *optimal*, sequential decision making under climate uncertainty.[40] By nature of being optimization models (instead of policy models), these complex models focus on calculating the optimal tax and not the social cost of carbon, which differ in that the former is the present value of marginal damages on the optimal emissions path rather than on the BAU emissions path.[41] While society faces the irreversibility of emissions on the BAU emissions path when abatement is essentially near zero (i.e., far below the optimal level even in the deterministic problem),[42] the stochastic dynamic optimization model must also account for a potential counteracting abatement cost irreversibility

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derived from the possibility to [emit] now or never. Traeger, C. P. (2014). On option values in environmental and resource economics. *Resource and Energy Economics*, *37*, 242-252, equation 5. Quasi-option value is the value of future learning conditional on delaying the emission decision, which mathematically equals the value of mitigation to the decision maker who anticipates learning less the value of mitigation to the decision maker who anticipates only the ability to delay his/her decision, and not learning. *Id.* The two values are related, such that real option value can be decomposed into:

$$\text{DPOV} = \text{Max}\{QOV + SOV - \text{Max}\{NPV, 0\}, 0\} = \text{Max}\{QOV + SOV - \text{SCC}, 0\}$$

where DPOV is the real option value, QOV is quasi-option value, SOV is simple option value (the value of the option to emit in the future condition on mitigating now), and NPV is the expected net present value of emitting the additional unit or the mean SCC in our case. *Id.*

[38] Even if society drastically reduced CO_2 emissions, CO_2 concentrations would continue to rise in the near future and many impacts would occur regardless due to lags in the climate system. Pindyck (2007), *supra* note 3. Uncertainty in environmental economics. *Review of environmental economics and policy*, *1*(1), 45-65.

[39] Pindyck (2007), *supra* note 3.

[40] Kann & Weyant, *supra* note 6; Pindyck (2007), *supra* note 3; Golub et al. (2014), *supra* note 3.

[41] Nordhaus (2014) makes this difference clear when he clarifies that "With an optimized climate policy…the SCC will equal the carbon price…In the more realistic case where climate policy is not optimized, it is conventional to measure the SCC as the marginal damage of emissions along the actual path. There is some inconsistency in the literature on the definition of the path along which the SCC should be calculated. This paper will generally define the SCC as the marginal damages along the baseline path of emissions and output and not along the optimized emissions path." Nordhaus, W. (2014). Estimates of the social cost of carbon: concepts and results from the DICE-2013R model and alternative approaches. *Journal of the Association of Environmental and Resource Economists*, *1*(1/2), 273-312.

[42] On the BAU path, emissions far exceed their optimal level even without considering uncertainty. As a consequence, society is likely to regret an additional emission of CO_2 in most future states of the world. Alternatively, society is unlikely to regret current abatement levels unless the extremely unlikely scenarios that there is little to no warming and/or damages from climate change.

– the sunk costs of investing in abatement technology if we learn that climate change is less severe than expected – by the nature of being on the optimal emissions path that balances the cost of emissions and abatement. In the optimal case, uncertainty and irreversibility of abatement *can theoretically* lead to a lower optimal emissions tax, unlike the social cost of carbon. The difference in the implication for the optimal tax and the SCC means that the stochastic dynamic modeling results are less applicable to the SCC.

What Can We Learn From New Literature on Stochastic Dynamic Programming Models?

Bearing in mind the limitations of stochastic dynamic modeling, some new research provides valuable insights that are relevant to calculation of the social cost of greenhouse gases. The new and growing stochastic dynamic optimization literature implies that the IWG's SCC estimates are downward biased. The literature is made up of three models – real option, finite horizon, and infinite horizon models – of which the infinite time horizon (i.e., stochastic dynamic programming (SDP)) models are the most comprehensive for analyzing the impact of uncertainty on optimal sequential abatement policies.[43] Recent computational advancements in SDP are helping overcome the need for strong simplifying assumptions in this literature for purpose of tractability. Traditionally, these simplifications led to unrealistically fast rates of learning – leading to incorrect outcomes – and difficulty in comparing results across papers (due to differing uncertain parameters, models of learning, and model types). Even so, newer methods still only allow for a handful of uncertain parameters compared to the hundreds of uncertain parameters in FUND and PAGE. Despite these limitations, the literature supports the above finding that the SCC, if anything, increases under uncertainty.[44]

First, uncertainty increases the optimal emissions tax under realistic parameter values and modeling scenarios. While the impact of uncertainty on the optimal emissions tax (relative to the deterministic problem) depends on the uncertain parameters considered, the type of learning, and the model type (real option, finite horizon, and infinite horizon), the optimal tax clearly increases when tipping points or black swan events are included in stochastic optimization problems.[45] For SDP models, uncertainty tends to strengthen the optimal emissions path relative to the determinist case even without tipping points,[46] and these results are strengthened under realistic

[43] Kann and Weyant (2000), *supra* note 6; Pindyck (2007), *supra* note 3; Golub et al. (2014), *supra* note 3.

[44] Kann and Weyant (2000), *supra* note 6; Pindyck (2007), *supra* note 3; Golub et al. (2014), *supra* note 3; Lemoine & Rudik (2017), *supra* note 3. Comparing the optimal tax to the mean SCC is made further difficult by the frequent use of DICE as the base from which most stochastic dynamic optimization models are built. As a consequence, deterministic model runs are frequently the base of comparison for these models. Lemoine & Rudik (2017), *supra* note 3.

[45] The real options literature tends to find an increase in the optimal emissions path under uncertainty relative to the deterministic case (Pindyck, 2007), though the opposite is true when modelers account for the possibility of large damages (i.e., tipping point or black swan events) even with a risk-neutral society (Pindyck, 2007; Golub et al., 2014). Solving finite horizon models employing non-recursive methods, modelers find that the results differ depending on the model of learning – the research demonstrates stricter emission paths under uncertainty without learning (with emission reductions up to 30% in some cases) and the impact under passive learning has a relatively small impact due the presence of sunken mitigation investment costs - except when tipping thresholds are included. *See* Golub et al. (2014), *supra* note 3.

[46] Using SDP, modelers find that uncertainty over the equilibrium climate sensitivity parameter generally increases the optimal tax by a small amount, though the magnitude of this impact is unclear. *See* Golub et al. (2014), *supra* note 3; Lemoine & Rudik (2017), *supra* note 3. Similarly, non-catastrophic damages can have opposing effects dependent on the parameters changed, though emissions appear to decline overall when you consider their uncertainty jointly.

preference assumptions.[47] Given that there is no counter-balancing tipping abatement cost,[48] the complete modeling of climate uncertainty – which fully accounts for tipping points and fat tails – increases the optimal tax. Uncertainty leads to a stricter optimal emissions policy even if with irreversible mitigation costs, highlighting that the SCC would also increase when factoring in risk aversion and irreversibility given that abatement costs are very low on the BAU emissions path.

Second, given the importance of catastrophic impacts under uncertainty (as shown in the previous paragraph), the full and accurate modeling of tipping points and unknown knowns is critical when modeling climate change. The most sophisticated climate-economic models of tipping points – which include the possibility of multiple correlated tipping points in stochastic dynamic IAMs – find an increase in the optimal tax by 100%[49] to 800%[50] relative to the deterministic case without them. More realistic modeling of tipping points will also increase the SCC.

Finally, improved modeling of preferences will amplify the impact of uncertainty on the SCC. Adopting Epstein-Zin preferences that disentangle risk aversion and time preferences can significantly increase the SCC under uncertainty.[51] Recent research has shown that accurate estimation of decisions under uncertainty crucially depends on distinguishing between risk and time preferences.[52] By conflating risk and time preferences, current models substantially understate the degree of risk aversion exhibited by most individuals, artificially lowering the SCC. Similarly, adopting ambiguity aversion increase the SCC, but to a much lesser extent than risk aversion.[53] Finally, allowing for the price of non-market goods to increase with their relative scarcity can amplify the positive effect that even small tipping points have on the SCC if the tipping point impacts non-market services.[54] Including more realistic preference assumptions in IAMs would further increase the SCC under uncertainty.

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[47] Pindyck (2007), *supra* note 3; Golub et al. (2014), *supra* note 3; Lemoine & Rudik (2017), *supra* note 3.

[48] Pindyck (2007), *supra* note 3.

[49] Lemoine, D., & Traeger, C. P. (2016b). Economics of tipping the climate dominoes. *Nature Climate Change*.

[50] Cai et al., 2016.

[51] Cai et al., 2016; Lemoine & Rudik (2017), *supra* note 3. The standard utility function adopted in IAMs with constant relative risk version implies that the elasticity of substitution equals the inversion of relative risk aversion. As a consequence, the society's preferences for the intra-generational distribution of consumption, the intergenerational distribution of consumption, and risk aversion hold a fixed relationship. For purposes of stochastic dynamic programming, this is problematic because this assumption conflates intertemporal consumption smoothing and risk aversion. Botzen, W. W., & van den Bergh, J. C. (2014). Specifications of social welfare in economic studies of climate policy: overview of criteria and related policy insights. *Environmental and Resource Economics*, *58*(1), 1-33. By adopting the Epstein-Zinn utility function which separates these two parameters, modelers can calibrate them according to empirical evidence. For example, Cai et al. (2016) replace the DICE risk aversion of 1.45 and elasticity parameter of 1/1.45 with values of 3.066 and 1.5, respectively.

[52] James Andreoni & Charles Sprenger, *Risk Preferences Are Not Time Preferences*, 102 AM. ECON. REV. 3357–3376 (2012).

[53] Lemoine, D., & Traeger, C. P. (2016b). Economics of tipping the climate dominoes. *Nature Climate Change*.; Lemoine & Rudik (2017), *supra* note 3.

[54] Typically, IAMs assume constant relative prices of consumption goods. Gerlagh, R., and B.C.C. Van der Zwaan. 2002. "Long-term substitutability between environmental and man-made goods." *Journal of Environmental Economics and Management 44*(2):329-345; Sterner, T., and U.M. Persson. 2008. "An Even Sterner Review: Introducing Relative Prices into the Discounting Debate." *Review of Environmental Economics and Policy 2*(1):61-76. By replacing the standard isoelastic utility function in IAMs with a nested CES utility function following Sterner and Persson (2008), Cai et al. (2015) find that even a relatively small tipping point (i.e., a 5% loss) can substantially increase the SCC in the stochastic dynamic setting. Cai, Y., Judd,

Introducing stochastic dynamic modeling (which captures option value and risk premiums), updating the representation of tipping points, and including more realistic preference structures in traditional IAMs will – as in the optimal tax – further increase the SCC under uncertainty

Conclusion: Uncertainty Raises the Social Cost of Greenhouse Gases

Overall, the message is clear: climate uncertainty is *never* a rationale for ignoring the SCC or shortening the time horizon of IAMs. Instead, our best estimates suggest that increased variability implies a higher SCC and a need for more stringent emission regulations.[55] Current omission of key features of the climate problem under uncertainty (the risk and climate premiums, option value, and fat tailed probability distributions) and incomplete modeling of tipping points imply that the SCC will further increase with the improved modeling of uncertainty in IAMs.

K. L., Lenton, T. M., Lontzek, T. S., & Narita, D. (2015). Environmental tipping points significantly affect the cost− benefit assessment of climate policies. *Proceedings of the National Academy of Sciences*, *112*(15), 4606-4611.

[55] Golub et al. (2014), *supra* note 3, states: "The most important general policy implication from the literature is that despite a wide variety of analytical approaches addressing different types of climate change uncertainty, none of those studies supports the argument that no action against climate change should be taken until uncertainty is resolved. On the contrary, uncertainty despite its resolution in the future is often found to favor a stricter policy." *See also* Comments from Robert Pindyck, to BLM, on the Social Cost of Methane in the Proposed Suspension of the Waste Prevention Rule (submitted Nov. 5, 2017) ("Specifically, my expert opinion about the uncertainty associated with Integrated Assessment Models (IAMs) was used to justify setting the SC-CH4 to zero until this uncertainty is resolved. That conclusion does not logically follow and I have rejected it in the past, and I reiterate my rejection of that view again here. While at this time we do not know the Social Cost of Carbon (SCC) or the Social Cost of Methane with precision, we do know that the correct values are well above zero…Because of my concerns about the IAMs used by the now-disbanded Interagency Working Group to compute the SCC and SC-CH4, I have undertaken two lines of research that do not rely on IAMs…[They lead] me to believe that the SCC is larger than the value estimated by the U.S. Government."

Technical Appendix: Discounting

The Underlying IAMs All Use a Consumption Discount Rate

Employing a consumption discount rate would also ensure that the U.S. government is consistent with the assumptions employed by the underlying IAM models: DICE, FUND, and PAGE. Each of these IAMs employs consumption discount rates calibrated using the standard Ramsey formula (Newell, 2017). In DICE-2010, the elasticity of the pure rate of time preference is 1.5 and an elasticity of the marginal utility of consumption (η) of 2.0. Together with its assumed per capita consumption growth path, the average discount rate over the next three hundred years is 2.4%.[127] However, more recent versions of DICE (DICE-2013R and DICE-2016) update η to 1.45; this implies an increase of the average discount rate over the timespan of the models to between 3.1% and 3.2% depending on the consumption growth path.[128] In FUND 3.8 and (the mode values in) PAGE09, both model parameters are equal to 1.0. Based on the assumed growth rate of the U.S. economy (without climate damages), the average U.S. discount rate in FUND 3.8 is 2.0% over the timespan of the model (without considering climate damages). Unlike FUND 3.8, PAGE09 specifies triangular distributions for both parameters with a pure rate of time preference of between 0.1 and 2 with a mean of 1.03 and an elasticity of the marginal utility of consumption of between 0.5 and 2 with a mean 1.17. Using the PAGE09's mode values (without accounting for climate damages), the average discount rate over the timespan of the models is approximately 3.3% with a range of 1.2% to 6.5%. Rounding up the annual growth rate over the last 50 years to approximately 2%,[129] the range of best estimates of the SDR implied in the short-run by these three models is approximately 3% (PAGE09's mode estimate and FUND 3.8) to 4.4% (DICE-2016), though the PAGE09 model alone implies a range of 1.1% to 6.0% with a central estimate of 3%. The range of potential consumption discount rates in these IAMs is relatively consistent with IWG (2010; 2013; 2016) in the short-run, though the discount rates of the IAMs employed by the IWG decline over time (due to declining growth rates over time) implying a potential upward bias to the IWG consumption discount rates.

A Declining Discount Rate Is Justified to Address Discount Rate Uncertainty

A strong consensus has developed in economics that the appropriate way to discount intergenerational benefits is through a declining discount rate (Arrow et al., 2013; Arrow et al., 2014; Gollier & Hammitt, 2014; Cropper et al., 2014).[130] Not only are declining discount rate theoretically correct, they are actionable (i.e., doable given our current knowledge) and consistent with OMB's *Circular A-4*. Perhaps the best reason to adopt a declining discount rate is

[127] Due to a slowing of global growth, DICE-2010 implies a declining discount rate schedule of 5.1% in 2015, 3.9% from 2015 to 2050; 2.9% from 2055 to 2100; 2.2% from 2105 to 2200, and 1.9% from 2205 to 2300. This would be a steeper decline if Nordhaus accounted for the positive and normative uncertainty underlying the SDR.

[128] Due to a slowing of global growth, DICE-2016 implies a declining discount rate schedule of 5.1% in 2015, 4.7% from 2015 to 2050; 4.1% from 2055 to 2100; 3.1% from 2105 to 2200, and 2.5% from 2205 to 2300.

[129] According to the World Bank, the average global and United States per capita growth rates were 1.7% and 1.9%, respectively.

[130] Arrow et al. (2014) at 160-161 states that "We have argued that theory provides compelling arguments for using a declining certainty-equivalent discount rate," and concludes the paper by stating "Establishing a procedure for estimating a [declining discount rate] for project analysis would be an improvement over the OMB's current practice of recommending fixed discount rates that are rarely updated."

the simple fact that there is considerable uncertainty around which discount rate to use. The uncertainty in the rate points directly to the need to use a declining rate, as the impact of the uncertainty grows exponentially over time such that the correct discount rate is not an arithmetic average of possible discount rates.[131] Uncertainty about future discount rates could stem from a number of sources particularly salient in the context of climate change, including uncertainty about future economic growth, consumption, the consumption rate of interest, and preferences. Additionally, economic theory shows that if there is debate or disagreement over which discount rate to use, this should lead to the use of a declining discount rate (Weitzman, 2001; Heal & Millner, 2014). Though, the range of potential discount rates is limited by theory to potential consumption discount rates (see earlier discussion), which is certainly less than 7%.

There Is a Consensus That Declining Discount Rates Are Appropriate for Intergenerational Discounting

Since the IWG undertook its initial analysis and before the most recent estimates of the SCC, a large and growing majority of leading climate economists' consensus (Arrow et al., 2013) has come out in favor of using a declining discount rate for climate damages to reflect long-term uncertainty in interest rates. This consensus view is held whether economists favor descriptive (i.e., market) or prescriptive (i.e., normative) approaches to discounting (Freeman et al., 2015). Several key papers (Arrow et al., 2013; Arrow et al., 2014; Gollier & Hammitt, 2014; Cropper et al., 2014) outline this consensus and present the arguments that strongly support the use of declining discount rates for long-term benefit-cost analysis in both the normative and positive contexts. Finally, in a recent survey of experts on the economics of climate change, Howard and Sylvan (2015) found that experts support using a declining discount rate relative to a constant discount rate at a ratio of approximately 2 to 1.

Economists have recently highlighted two main motivations for using a declining discount rate, which we elaborate on in what follows. First, if the discount rate for a project is fixed but uncertain, then the certainty-equivalent discount rate will decline over time, meaning that benefits should be discounted using a declining rate.[132] Second, uncertainty about the growth rate of consumption or output also implies that a declining discount rate should be used, so long as shocks to consumption are positively correlated over time.[133] In addition to these two arguments, other motivations for declining discount rates have long been recognized. For instance, if the

[131] Karp (2005) states that mathematical "intuition for this result is that as [time] increases, smaller values of r in the support of the distribution are relatively more important in determining the expectation of e−rt" where r is the constant discount rate." Or as Hepburn et al. (2003) puts it, "The intuition behind this idea is that scenarios with a higher discount rate are given less weight as time passes, precisely because their discount factor is falling more rapidly" over time.

[132] This argument was first developed in Weitzman (1998) and Weitzman (2001).

[133] *See, e.g.*, Gollier (2009).

growth rate of consumption declines over time, the Ramsey rule[134] for discounting will lead to a declining discount rate.[135]

In the descriptive setting adopted by the IWG (2010), economists have demonstrated that calculating the expected net present value of a project is equivalent to discounting at a declining certainty equivalent discount rate when (1) discount rates are uncertain, and (2) discount rates are positively correlated (Arrow et al., 2014 at 157). Real consumption interest rates are uncertain given that there are no multi-generation assets to reflect long-term discount rates and the real returns to all assets—including government bonds—are risky due to inflation and default risk (Gollier & Hammitt, 2014). Furthermore, recent empirical work analyzing U.S. government bonds demonstrates that they are positively correlated over time; this empirical work has estimated several declining discount rate schedules that the IWG can use (Cropper et al., 2014; 2014; Arrow et al., 2013; Arrow et al., 2014; Jouini and Napp, 2014; Freeman et al. 2015).

Currently when evaluating projects, the U.S. government applies the descriptive approach using constant rates of 3% and 7% based on the private rates of return on consumer savings and capital investments. As discussed previously, applying a capital discount rate to climate change costs and benefits is inappropriate (Newell, 2017). Instead, analysis should focus on the uncertainty underlying the future consumption discount rate (Newell, 2017). Past U.S. government analyses (IWG, 2010; IWG, 2013; IWG, 2016) modeled three consumption discount rates reflecting this uncertainty. If the U.S. government correctly returns its focus on multiple consumption discount rates, then the expected net present value argument given above implies that a declining discount rate is the appropriate way to perform discounting. As an alternative, given that the Ramsey discount rate approach is the appropriate methodology in intergenerational settings, the U.S. government could use a fixed, low discount rate as an approximation of the Ramsey equation following the recommendation of Marten et al. (2015); see our discussion on Martin et al. 2015). This is roughly IWG (2010)'s goal for using the constant 2.5% discount rate.

If the normative approach to discounting is used in the future (i.e., the current approach of IAMs), economists have demonstrated that an extended Ramsey rule[136] implies a declining

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[134] The Ramsey discount rate equation for the social discount rate is $r = \delta + \eta * g$ where r is the social discount rate, δ is the pure rate of time preference, η is the aversion to inter-generational inequality, and g is the growth rate of per capita consumption. For the original development, *see*, Ramsey, F. P. (1928). A Mathematical Theory of Saving. *The Economic Journal*, *38*(152).

[135] Higher growth rates lead to higher discounting of the future in the Ramsey model because growth will make future generations wealthier. If marginal utility of consumption declines in consumption, then, one should more heavily discount consumption gains by wealthier generations. Thus, if growth rates decline over time, then the rate at which the future is discounted should also decline. *See*, *e.g.*, Arrow et al. (2014) at 148. It is standard in IAMs to assume that the growth rate of consumption will fall over time. *See*, *e.g.*, Nordhaus (2017) at 1519, "Growth in global per capita output over the 1980–2015 period was 2.2% per year. Growth in global per capita output from 2015 to 2050 is projected at 2.1% per year, whereas that to 2100 is projected at 1.9% per year." Similarly, Hope (2011) at 22 assumes that growth will decline. For instance, in the U.S., growth is 1.9% per year in 2008 and declines to 1.7% per year by 2040. Using data provided by Dr. David Anthoff (one of the founders of FUND), FUND assumes that the global growth rate was 1.8% per year from 1980–2015 period, 1.4% per year from 2015 to 2050 and 2015 to 2100, and then dropping to 1.0% from 2100 to 2200 and then 0.7% from 2200 to 2300.

[136] If the future growth of consumption is uncertainty with mean μ and variance σ^2, an extended Ramsey equation $r = \delta + \eta * \mu - 0.5\eta^2\sigma^2$ applies where r is the social discount rate, δ is the pure rate of time preference, η is the aversion to inter-generational inequality, and g is the growth rate of per capita consumption. Gollier (2012, Chapter 3) shows that we can rewrite the extended discount rate as $r = \delta + \eta * g - 0.5\eta(\eta + 1)\sigma^2$ where g is the growth rate of expected consumption and $\eta + 1$ is prudence.

discount rate when (1) the growth rate of per capita consumption is stochastic,[137] and (2) consumption shocks are positively correlated over time (or their mean or variances are uncertain) (Arrow et al., 2013; Arrow et al., 2014; Gollier & Hammitt, 2014; Cropper et al., 2014).[138] While a constant adjustment downwards (known as the precautionary effect[139]) can be theoretically correct when growth rates are independent and identically distributed (Cropper et al., 2014), empirical evidence supports the two above assumptions for the United States, thus implying a declining discount rate (Cropper et al., 2014; Arrow et al., 2014; IPCC, 2014).[140] We should further expect this positive correlation to strengthen over time due to the negative impact of climate change on consumption, as climate change causes an uncertain permanent reduction in consumption (Gollier, 2009).[141]

Several papers have estimated declining discount rate schedules for specific values of the pure rate of time preference and elasticity of marginal utility of consumption (e.g., Arrow et al., 2014), though recent work demonstrates that the precautionary effect increases and discount rates decrease further when catastrophic economic risks (such as the Great Depression and the 2008 housing crisis) are modeled (Gollier & Hammitt, 2014; Arrow et al., 2014). It should be noted that this decline in discount rates due to uncertainty in the global growth path is in addition to that resulting from a declining central growth path over time (Nordhaus, 2014; Marten, 2015).[142]

Additionally, a related literature has developed over the last decade demonstrating that normative uncertainty (i.e., heterogeneity) over the pure rate of time preference (δ)—a measure of impatience—also leads to a declining social discount rate (Arrow et al., 2014; Cropper et al., 2014; Freeman and Groom, 2016). Despite individuals differing in their pure rate of time preference (Gollier and Zeckhauser, 2005), an equilibrium (consumption) discount exists in the

[137] The IWG assumption of five possible socio-economic scenarios implies an uncertain growth path.

[138] The intuition of this result requires us to recognize that the social planner is prudent in these models (i.e., saves more when faces riskier income). When there is a positive correlation between growth rates in per capita consumption, the representative agent faces more cumulative risk over time with respect to the "duration of the time spent in the bad state." (Gollier et al., 2008). In other words, "the existence of a positive correlation in the changes in consumption tends to magnify the long-term risk compared to short-term risks. This induces the prudent representative agent to purchase more zero-coupon bonds with a long maturity, thereby reducing the equilibrium long-term rate." (Gollier, 2007). Mathematically, the intuition is that under prudence, the third term in the extended Ramsey equation (*see* footnote 323) is negative, and a "positive [first-degree stochastic] correlation in changes in consumption raises the riskiness of consumption at date T, without changing its expected value. Under prudence, this reduces the interest rate associated to maturity T" (Gollier et al., 2007) by "increasing the strength of the precautionary effect" in the extended Ramsey equation (Arrow et al., 2014; Cropper et al., 2014).

[139] The precautionary effect measures aversion to future "wiggles" in consumption (i.e., preference for consumption smoothing) (Traeger, 2014).

[140] Essentially, the precautionary effect increases over time when shocks to the growth rate are positively correlated, implying that future societies require higher returns to face the additional uncertainty (Cropper et al., 2014; Arrow et al., 2014; IPCC, 2014).

[141] Due to the deep uncertainty characterizing future climate damages, some analysts argue that the stochastic processes underlying the long-run consumption growth path cannot be econometrically estimated (Weitzman, 2007; Gollier, 2012). In other words, economic damages, and thus future economic growth, are ambiguous. Agents must then form subjectivity probabilities, which may be better interpreted as a belief (Cropper et al., 2014). Again, theory shows that ambiguity leads to a declining discount rate schedule by Jensen's inequality (Cropper et al., 2014).

[142] A common assumption in IAMs is that global growth will slow over time leading to a declining discount rate schedule over time; *see* footnote 7. Uncertainty over future consumption growth and heterogeneous preferences (discussed below) would lead to a more rapid decline in the social discount rate.

economy. In the context of IAMs, modelers aggregate social preferences (often measured using surveyed experts) by calibrating the preferences of a representative agent to this equilibrium (Millner and Heal, 2015; Freeman and Groom, 2016). The literature generally finds a declining social discount rate due to a declining collective pure rate of time preference (Gollier and Zeckhauser, 2005; Jouini et al., 2010; Jouini and Napp, 2014; Freeman and Groom, 2016).[143] The heterogeneity of preferences and the uncertainty surrounding economic growth hold simultaneously (Jouini et al., 2010; Jouini and Napp, 2014), leading to potentially two sources of declining discount rates in the normative context.

Declining Rates Are Actionable and Time-Consistent

There are multiple declining discount rate schedules from which the U.S. government can choose, of which several are provided in Arrow et al. (2014) and Cropper et al. (2014). One possible declining interest rate schedule for consideration by the IWG is the one proposed by Weitzman (2001).[144] It is derived from a broad survey of top economists in context of climate change, and explicitly incorporates arguments around interest rate uncertainty.[145] Other declining discount rate schedules include Newell and Pizer (2003); Groom et al. (2007); Freeman et al. (2015). Many leading economists support the United States government adopting a declining discount rate schedule (Arrow et al., 2014; Cropper et al., 2014). Moreover, the United States would not be alone in using a declining discount rate. It is standard practice for the United Kingdom and French governments, among others (Gollier & Hammitt, 2014; Cropper et al., 2014). The U.K. schedule explicitly subtracts out an estimated time preference.[146] France's schedule is roughly similar to the United Kingdom's. Importantly, all of these discount rate schedules yield lower present values than the constant 2.5% discount rate employed by IWG (2010), suggesting that even the lowest discount rate evaluated by the IWG is too high.[147] The consensus of leading economists is that a declining discount rate schedule should be used, harmonious with the approach of other countries like the United Kingdom. Adopting such a

[143] The intuition for declining discount rates due to heterogeneous pure rates of time preference is laid out in Gollier and Zeckhauser (2005). In equilibrium, the least patient individuals trade future consumption to the most patient individuals for current consumption, subject to the relative value of their tolerance for consumption fluctuations. Thus, while public policies in the near term mostly impact the most impatient individuals (i.e., the individuals with the most consumption in the near term), long-run public policies in the distant future are mostly going to impact the most patient individuals (i.e., the individuals with the most consumption in the long-run).

[144] Weitzman (2001)'s schedule is as follows: 4% for 1-5 years; 3% for 6-25 years; 2% for 26-75 years; 1% for 76-300 years; and 0% for 300+ years.

[145] Freeman and Groom (2014) demonstrate that this schedule only holds if the heterogeneous responses to the survey were due to differing ethical interpretations of the corresponding discount rate question. A recent survey by Drupp et al. (2015) – which includes Freeman and Groom as co-authors – supports the Weitzman (2001) assumption.

[146] The U.K. declining discount rate schedule that subtracts out a time preference value is as follows (Lowe, 2008): 3.00% for 0-30 years; 2.57% for 31-75 years; 2.14% for 76-125 years; 1.71% for 126- 200 years; 1.29% for 201- 300 years; and 0.86% for 301+ years.

[147] Using the IWG's 2010 SCC model, Johnson and Hope (2012) find that the U.K. and Weitzman schedules yield SCCs of $55 and $175 per ton of CO_2, respectively, compared to $35 at a 2.5% discount rate. Because the 2.5% discount rate was included by the IWG (2010) to proxy for a declining discount rate, this result indicates that constant discount rate equivalents may be insufficient to address declining discount rates.

schedule would likely increase the SCC substantially from the administration's 3% estimate, potentially up to two to three fold (Arrow et al., 2013; Arrow et al., 2014; Freeman et al., 2015).

A declining discount rate motived by discount rate or growth rate uncertainty avoids the time inconsistency problem that can arise if a declining pure rate of time preference (δ) is used. *Circular A-4* cautions that "[u]sing the same discount rate across generations has the advantage of preventing time-inconsistency problems."[148] A time inconsistent decision is one where a decision maker changes his or her plan over time, solely because time has passed. For instance, consider a decision maker choosing whether to make an investment that involves an up-front payment followed by future benefits. A time consistent decision maker would invest in the project if it had a positive net-present value, and that decision would be the same whether it was made 10 years before investment or 1 year before investment. A time inconsistent decision maker might change his or her mind as the date of the investment arrived, despite no new information becoming available. Consider a decision maker who has a declining pure rate of time preference (δ) trying to decide whether to invest in a project that has large up-front costs followed by future benefits. Ten years prior to the date of investment, the decision maker will believe that this project is a relatively unattractive investment because both the benefits and costs would be discounted at a low rate. Closer to the date of investment, however, the costs would be relatively highly discounted, possibly leading to a reversal of the individual's decision. Again, the discount rate schedule is time consistent as long as δ is constant.

The arguments provided here for using a declining consumption discount rate are not subject to this time inconsistency critique. First, time inconsistency occurs if the decision maker has a declining pure rate of time preference, not due to a decreasing discount rate term structure.[149] Second, uncertainty about growth or the discount rate avoids time inconsistency because uncertainty is only resolved in the future, after investment decisions have already been made. As the NAS (2017) notes, "One objection frequently made to the use of a declining discount rate is that it may lead to problems of time inconsistency….This apparent inconsistency is not in fact inconsistent….At present, no one knows what the distribution of future growth rates…will be; it may be different or the same as the distribution in 2015. Even if it turns out to be the same as the distribution in 2015, that realization is new information that was not available in 2015."[150]

We should note that time-inconsistency is not a reason to ignore heterogeneity (i.e., normative uncertainty) over the pure rate of time preference (δ). If the efficient declining discount rate schedule is time-inconsistent, the appropriate solution is to select the best time-consistent policy. Millner and Heal (2014) do just this by demonstrating that a voting procedure – whereby the median voter determines the collective preference – is: (1) time consistent, (2) welfare enhancing relative to the non-commitment, time-inconsistent approach, and (3) preferred by a majority of

[148] *Circular A-4* at 35.

[149] Gollier (2012) states "It is often suggested in the literature that economic agents are time inconsistent if the term structure of the discount rate is decreasing. This is not the case. What is crucial for time consistency is the constancy of the rate of impatience, which is a cornerstone of the classic analysis presented in this book. We have seen that this assumption is compatible with a declining monetary discount rate."

[150] National Academies of Sciences, Engineering, and Medicine, Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide 182 (2017).

agents relative to all other time-consistent plans. Due to the right skewed distribution of the pure rate of time preference and the social discount rate as shown in all previous surveys (Weitzman, 2001; Drupp et al., 2015; Howard and Sylvan, 2015), the median is less than the mean social discount rate (and pure rate of time preference); the mean social discount rate is what holds in the very short-run under various aggregation methods, such as Weitzman (2001) and Freeman and Groom (2015). Combining an uncertain growth rate and heterogeneous preference together implies a declining discount rate starting at a lower value in the short-run. In addition to the reasons discussed earlier in the comments, this is another reason to exclude a discount rate as high as 7%.

There Is an Economic Consensus on the Appropriateness of Employing a Consumption Discount Rate (and the Inappropriateness of a Capital Discount Rate) in the Context of Climate Change

There is a strong consensus among economists that it is theoretically correct to use consumption discount rates in the intergenerational setting of climate change, such as in the calculation of the SCC. Similarly, there is a strong consensus that a capital discount rate is inappropriate according to "good economics" (Newell, 2017).[151] This consensus holds across panels of experts on the social cost of carbon (NAS, 2017); surveys of experts on climate change and discount rates (Weitzman, 2001; Drupp et al., 2015; Howard and Sylvan, 2015; and Pindyck, 2016); the three most commonly cited IAMs employed in calculating the federal SCC; and the government's own analysis (IWG, 2010; CEA, 2017). For more analysis of this issue, see the discussion in the main body our Comments on the inappropriateness of using a discount rate premised on the return to capital in intergenerational settings.

[151] The former co-chair of the National Academy of Sciences' Committee on Assessing Approaches to Updating the Social Cost of Carbon – Richard Newell (2017) – states that "[t]hough the addition of an estimate calculated using a 7 percent discount rate is consistent with past regulatory guidance under OMB Circular A-4, there are good reasons to think that such a high discount rate is inappropriate for use in estimating the SCC…It is clearly inappropriate, therefore, to use such modeling results with OMB's 7 percent discount rate, which is intended to represent the historical before-tax return on private capital…This is a case where unconsidered adherence to the letter of OMB's simplified discounting approach yields results that are inconsistent with and ungrounded from good economics."

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