At What Cost? Examining the Social Cost of Carbon

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1. The Social Cost of Carbon (SCC) is a tool used by policymakers to quantify the economic damages associated with carbon dioxide emissions. In my work at The Heritage Foundation, we have rigorously examined two of the three models that the Obama Administration's Interagency Working Group (IWG) used to estimate the SCC. This work has been published both at The Heritage Foundation as well as the peer reviewed literature.

2. The models are extremely sensitive to very reasonable changes to assumptions. As a result, these models can be manipulated to produce a wide range of costs.

3. The models are based on projections 300 years into the future. It is difficult to envision what the country would look like decades, let alone centuries into the future. Upon changing this time span to the less unrealistic time horizon of 150 years into the future, we found that the estimates plummet by as much as 25% in some instances.

4. The Administration's analysis of the SCC assumes an outdated climate sensitivity specification based on a paper published ten years ago in the journal *Science.* This specification is no longer defensible. We have re-estimated the SCC using more up-to date distributions and found reductions of up to nearly 200%. The use of this outdated distribution thus artificially inflates the calculated value of the SCC.

5. The Office of Management and Budget stipulated in Circular A-4 that a 7% discount rate be used as part of cost-benefit analysis. The Administration's IWG ignored this recommendation. We reran the models using a 7% discount rate and found that the SCC drops by over 75% when compared to a 3% discount rate.

6. Under a variety of assumptions, including those made by the IWG itself, one of its three predictive models shows that the SCC has a non-trivial probability of being negative. This would suggest that there are actually benefits of CO2 emissions. Under some very reasonable assumptions, this probability (~70%) can be quite substantial.

7. The GHG regulations implied by the IWG's use of these models would result in significant damage to the economy. Our analysis finds that, by 2035, the country would experience an average employment shortfall of 400,000 lost jobs, a total loss of income over $20,000 for a family of four, a 13-20% increase in electricity prices, and an aggregate $2.5 trillion loss in GDP.

8. In addition to the above damages, these regulations would result in negligible environmental benefits (<0.2°C temperature mitigation and less than 2 cm of sea level reductions).

The Heritage Foundation

CONGRESSIONAL TESTIMONY

Methods and Parameters Used to Establish the Social Cost of Carbon

Testimony before the Subcomittee on Environment and Oversight

Committee on Science and Technology

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Chairman Biggs, Ranking Member Bonamici, and other Members of the subcommittee, thank you for the opportunity to testify about the social cost of carbon. My name is Kevin Dayaratna. I am the Senior Statistician and Research Programmer at The Heritage Foundation. The views I express in this testimony are my own and should not be construed as representing any official position of The Heritage Foundation.

For much of the past decade, the federal government has strived to expand regulations across the energy sector of the economy. One of the primary justifications for doing so has been the social cost of carbon (SCC), which is defined as the economic damages associated with a metric ton of carbon dioxide (CO_2) emissions summed across a particular time horizon.[1]

The Models

There are three primary statistical models that the Interagency Working Group (IWG) has used to estimate the SCC—the Dynamic Integrated Climate-Economy (DICE) model, the Framework for Uncertainty, Negotiation and Distribution (FUND) model, and the Policy Analysis of the Greenhouse Effect (PAGE) model.[2] Over the last several years at The Heritage Foundation, my colleagues and I have used the DICE and FUND models, testing their sensitivity to a variety of important assumptions. Our research, published as Heritage Foundation publications, in the peer-reviewed literature, and discussed in my prior congressional testimony, has repeatedly illustrated that although these models might be interesting academic exercises, they are extremely sensitive to very reasonable changes to assumptions.[3] These models can thus be manipulated by user-selected assumptions, and are therefore not suitable for guiding regulatory policy.

These models are estimated by Monte Carlo simulation. The general idea behind Monte Carlo simulation is that since some aspects of the models are random, the models are repeatedly estimated to generate a spectrum of probable outcomes. As a result of principles in probability theory, repeated estimation for a sufficient amount of time provides a reasonable characterization of the SCC's distributional properties.

As with any statistical model, however, these models are grounded by assumptions. In our work, my colleagues and I have rigorously examined three important assumptions: the choice of a discount rate, a time horizon, and the specification of an equilibrium climate sensitivity distribution.

TABLE 1

DICE Model Average SCC – Baseline, End Year 2300

Year	Discount Rate - 2.50%	Discount Rate - 3%	Discount Rate - 5%	Discount Rate - 7%
2010	$46.58	$30.04	$8.81	$4.02
2020	$56.92	$37.79	$12.10	$5.87
2030	$66.53	$45.15	$15.33	$7.70
2040	$76.96	$53.26	$19.02	$9.85
2050	$87.70	$61.72	$23.06	$12.25

SOURCE: Kevin Dayaratna, Ross McKitrick, and David Kreutzer, "Empirically-Constrained Climate Sensitivity and the Social Cost of Carbon," *Climate Change Economics*.

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TABLE 2

FUND Model Average SCC – Baseline, End Year 2300

Year	Discount Rate - 2.50%	Discount Rate - 3%	Discount Rate - 5%	Discount Rate - 7%
2010	$29.69	$16.98	$1.87	-$0.53
2020	$32.90	$19.33	$2.54	-$0.37
2030	$36.16	$21.78	$3.31	-$0.13
2040	$39.53	$24.36	$4.21	$0.19
2050	$42.98	$27.06	$5.25	$0.63

SOURCE: Kevin Dayaratna, Ross McKitrick, and David Kreutzer, "Empirically-Constrained Climate Sensitivity and the Social Cost of Carbon," *Climate Change Economics*.

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Discount Rate

As people prefer benefits sooner rather than later and costs later rather than sooner, discount rates enable us to normalize inequalities regarding long-term investments. The Environmental Protection Agency (EPA) has run these models using 2.5 percent, 3 percent, and 5 percent discount rates despite the fact that the Office of Management and Budget guidance in Circular A-4 has specifically stipulated that a 7 percent discount rate be used as well.[4] In my research, we re-estimated these models using a 7 percent discount rate in a variety of publications, holding constant all other assumptions made by the IWG. Tables 1 and 2 are our results recently accepted for publication in the peer-reviewed journal *Climate Change Economics*.

As we can see, the SCC estimates are drastically reduced under the use of a 7 percent discount rate. In fact, under the FUND model, the estimates are negative, suggesting that there are actually benefits to CO_2 emissions. These changes in the discount rate can cause the SCC to drop by as much as 80 percent or more.

Time Horizon

It is essentially impossible to forecast technological change decades, let alone centuries, into the future. Regardless, however, these SCC models are based on projections 300 years into the future. In my work at Heritage, I have changed this time horizon to the significantly less, albeit still unrealistic,

TABLE 3

DICE Model Average SCC - End Year 2150

Year	Discount Rate - 2.50%	Discount Rate - 3%	Discount Rate - 5%	Discount Rate - 7%
2010	$36.78	$26.01	$8.66	$4.01
2020	$44.41	$32.38	$11.85	$5.85
2030	$50.82	$38.00	$14.92	$7.67
2040	$57.17	$43.79	$18.36	$9.79
2050	$62.81	$49.20	$22.00	$12.13

SOURCE: Kevin D. Dayaratna and David W. Kreutzer, "Loaded DICE: An EPA Model Not Ready for the Big Game," Heritage Foundation Backgrounder No. 2860, November 21, 2013, http://www.heritage.org/environment/report/loaded-dice-epa-model-not-ready-the-big-game.

time horizon of 150 years into the future, and we obtained the following results for the DICE model in our work published in 2013 (see Table 3).[5]

Clearly, the SCC estimates drop substantially as a result of changing the end year (in some cases by over 25 percent).

Equilibrium Climate Sensitivity (ECS) Distribution

These models of course take into account assumptions regarding the planet's climate sensitivity. The real question, however, is the degree of accuracy statistical models have at doing so. Dr. John Christy testified in both 2013 and 2016 regarding the efficacy of climate change projections and juxtaposed them against reality. In his testimony, Christy exposed the sheer inadequacy of the Intergovernmental Panel on Climate Change's (IPCC's) models in forecasting global temperatures.[6]

The climate specification used in estimating the SCC is that of an equilibrium climate sensitivity (ECS) distribution. These distributions probabilistically quantify the earth's temperature response to a doubling of CO_2 concentrations. The ECS distribution used by the IWG is based on a paper published in the journal *Science* ten years ago by Gerard Roe and Marcia Baker. This non-empirical distribution, calibrated by the IWG based on assumptions that the group decided on climate change in conjunction with IPCC recommendations, has been deemed to be "no longer scientifically defensible."[7] Since then, a variety of newer and more up-to-date distributions have been suggested in the peer-reviewed literature. Many of these distributions, in fact, suggest lower probabilities of extreme global warming in response to CO_2 concentrations. Below are a few such distributions:[8]

The area under the curve between two temperature points depicts the probability that the Earth's temperature will increase between those amounts in response to a doubling of CO_2 concentrations. Thus, the area under the curve from 4 degrees Celsius (C) onwards (known as a "tail probability") provides the probability that the Earth's temperature will warm by more than 4 degrees C in response to a doubling of CO_2 concentrations. Note that the more up-to-date ECS distributions (Otto et al., 2013; Lewis, 2013; Lewis and Curry, 2015; see chart on p. 7) have significantly lower tail probabilities (5 to 700 times lower regarding temperature increases above 4 degrees C) than the outdated Roe-Baker (2007) distribution used by the IWG. In our research published in *Climate Change Economics*, we re-estimated the SCC having used these more up-to-date ECS distributions and obtained the following results (see Tables 4 and 5).[9]

Again, we notice drastically lower estimates of the SCC using these more up-to-date ECS distributions. These results are not surprising—the IWG's estimates of the SCC were based on outdated assumptions that overstated the probabilities of extreme global warming, which artificially inflated their estimates of the SCC.

Negativity

When people talk about the social cost of carbon, they tend to think of damages. Not all of these models,

TABLE 4

DICE Model Average SCC – ECS Distribution Updated in Accordance with Lewis and Curry (2015), End Year 2300

Year	Discount Rate - 2.50%	Discount Rate - 3%	Discount Rate - 5%	Discount Rate - 7%
2010	$23.62	$15.62	$5.03	$2.48
2020	$28.92	$19.66	$6.86	$3.57
2030	$33.95	$23.56	$8.67	$4.65
2040	$39.47	$27.88	$10.74	$5.91
2050	$45.34	$32.51	$13.03	$7.32

SOURCE: Kevin Dayaratna, Ross McKitrick, and David Kreutzer, "Empirically-Constrained Climate Sensitivity and the Social Cost of Carbon," *Climate Change Economics*.

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TABLE 5

FUND Model Average SCC – ECS Distribution Updated in Accordance with Lewis and Curry (2015), End Year 2300

Year	Discount Rate - 2.50%	Discount Rate - 3%	Discount Rate - 5%	Discount Rate - 7%
2010	$5.25	$2.78	-$0.65	-$1.12
2020	$5.86	$3.33	-$0.47	-$1.10
2030	$6.45	$3.90	-$0.19	-$1.01
2040	$7.02	$4.49	-$0.18	-$0.82
2050	$7.53	$5.09	$0.64	-$0.53

SOURCE: Kevin Dayaratna, Ross McKitrick, and David Kreutzer, "Empirically-Constrained Climate Sensitivity and the Social Cost of Carbon," *Climate Change Economics*.

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however, suggest that there are always damages associated with CO_2 emissions. The FUND model, in fact, allows for the SCC to be negative based on feedback mechanisms due to CO_2 emissions. In my research at The Heritage Foundation, we actually calculated the probability of a negative SCC under a variety of assumptions. Below are some of our results published at Heritage as well as in the peer-reviwed journal *Climate Change Economics* (see Tables 6, 7, 8, and 9).[10]

As the above statistics illustrate, under a very reasonable set of assumptions, the SCC is overwhelmingly likely to be negative, which would suggest the government should, in fact, subsidize (not limit) CO_2 emissions. Of course, I by no means use these results to suggest that the government should actually subsidize CO_2 emissions, but rather to illustrate the extreme sensitivity of these models to reasonable changes to assumptions and can thus be quite easily fixed by policymakers.

Economic Growth

In 2013, Professor Robert Pindyck of MIT has summarized many of the issues associated with integrated assessment modeling:

TABLE 6

FUND Model Probability of Negative SCC – ECS Distribution Based on Outdated Roe–Baker (2007) Distribution, End Year 2300

Year	Discount Rate - 2.50%	Discount Rate - 3%	Discount Rate - 5%	Discount Rate - 7%
2010	0.087	0.121	0.372	0.642
2020	0.084	0.115	0.344	0.601
2030	0.08	0.108	0.312	0.555
2040	0.075	0.101	0.282	0.507
2050	0.071	0.093	0.251	0.455

SOURCE: Kevin Dayaratna, Ross McKitrick, and David Kreutzer, "Empirically-Constrained Climate Sensitivity and the Social Cost of Carbon," *Climate Change Economics*.

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TABLE 7

FUND Model Probability of Negative SCC – ECS Distribution Updated in Accordance with Otto et al. (2013), End Year 2300

Year	Discount Rate - 2.50%	Discount Rate - 3%	Discount Rate - 5%	Discount Rate - 7%
2010	0.278	0.321	0.529	0.701
2020	0.268	0.306	0.496	0.661
2030	0.255	0.291	0.461	0.619
2040	0.244	0.274	0.425	0.571
2050	0.228	0.256	0.386	0.517

SOURCE: Kevin D. Dayaratna and David W. Kreutzer, "Unfounded FUND: Yet Another EPA Model Not Ready for the Big Game," Heritage Foundation Backgrounder No. 2897, April 29, 2014, http://www.heritage.org/environment/report/unfounded-fund-yet-another-epa-model-not-ready-the-big-game.

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Given all of the effort that has gone into developing and using IAMs, have they helped us resolve the wide disagreement over the size of the SCC? Is the U.S. government estimate of $21 per ton (or the updated estimate of $33 per ton) a reliable or otherwise useful number? What have these IAMs (and related models) told us? I will argue that the answer is very little. As I discuss below, the models are so deeply flawed as to be close to useless as tools for policy analysis. Worse yet, precision that is simply illusory, and can be highly misleading.

> ...[A]n IAM-based analysis suggests a level of knowledge and precision that is nonexistent, and allows the modeler to obtain almost any desired result because key inputs can be chosen arbitrarily.[11]

What is interesting is the relationship these models have amongst SCC, temperature, and economic growth. Intuitively, one would believe that if there are indeed so-called social costs of CO_2 emissions, then they would result literal economic damages (that would be manifested in gross domestic product

TABLE 8

FUND Model Probability of Negative SCC – ECS Distribution Updated in Accordance with Lewis (2013), End Year 2300

Year	Discount Rate - 2.50%	Discount Rate - 3%	Discount Rate - 5%	Discount Rate - 7%
2010	0.39	0.431	0.598	0.722
2020	0.375	0.411	0.565	0.685
2030	0.361	0.392	0.53	0.645
2040	0.344	0.371	0.491	0.598
2050	0.326	0.349	0.449	0.545

SOURCE: Kevin D. Dayaratna and David W. Kreutzer, "Unfounded FUND: Yet Another EPA Model Not Ready for the Big Game," Heritage Foundation Backgrounder No. 2897, April 29, 2014, http://www.heritage.org/environment/report/unfounded-fund-yet-another-epa-model-not-ready-the-big-game.

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TABLE 9

FUND Model Probability of Negative SCC – ECS Distribution Updated in Accordance with Lewis (2013), End Year 2300

Year	Discount Rate - 2.50%	Discount Rate - 3%	Discount Rate - 5%	Discount Rate - 7%
2010	0.416	0.45	0.601	0.73
2020	0.402	0.432	0.57	0.69
2030	0.388	0.414	0.536	0.646
2040	0.371	0.394	0.496	0.597
2050	0.354	0.372	0.456	0.542

SOURCE: Kevin Dayaratna, Ross McKitrick, and David Kreutzer, "Empirically-Constrained Climate Sensitivity and the Social Cost of Carbon," *Climate Change Economics*.

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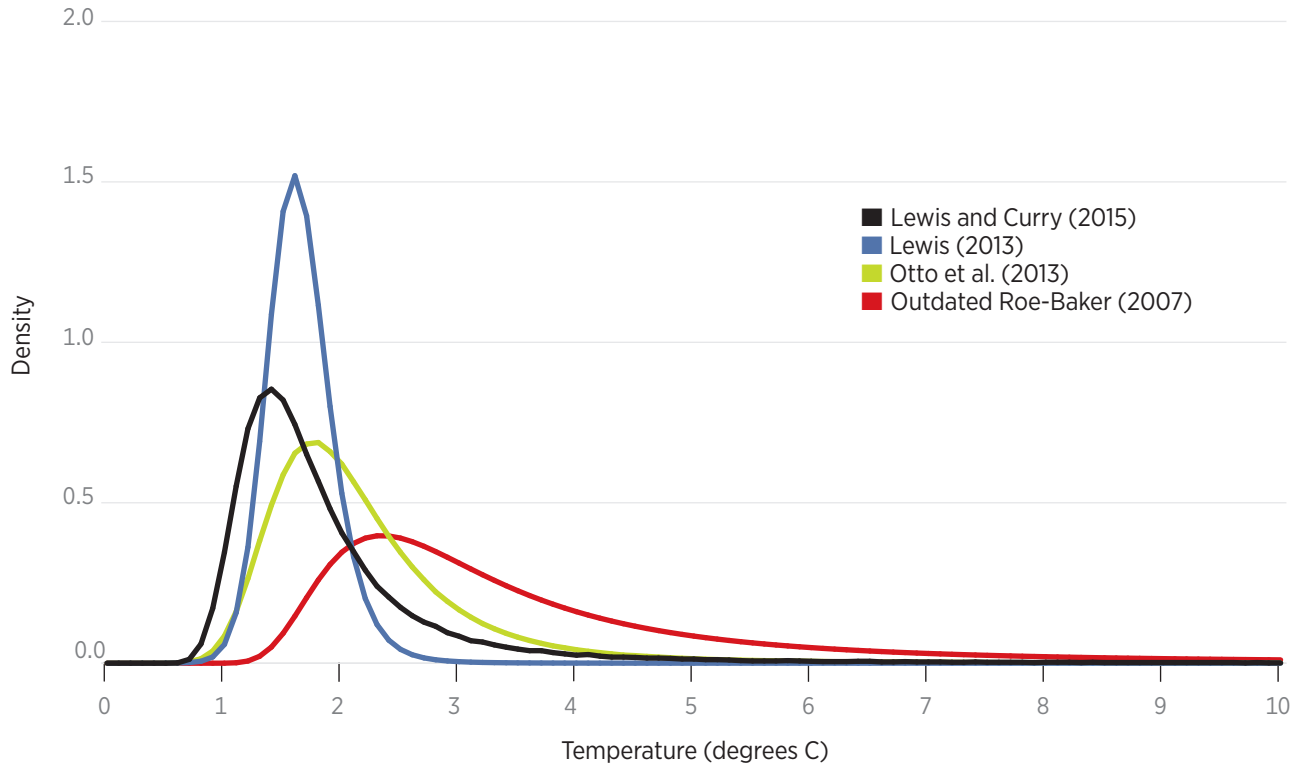
(GDP)) in the long run. These models, however, operate in a manner that is precisely the contrary. The models estimate the SCC after averaging simulations run across five different economic-growth scenarios. The plots on pages 8 and 9 provide temperature and GDP projections based on the DICE model from our 2013 analysis:[12]

The wealthiest society depicted by IMAGE has the greatest SCC estimate of the economic-growth scenarios, but only a modest amount of temperature change. As a result, the implication would be to sacrifice more economically for not necessarily more global warming. These figures clearly demonstrate the sheer absurdity associated with the DICE model.

The Social Costs of Methane and Nitrous Oxide

The EPA has also proposed similar models to quantify the social costs of methane (SCM) and nitrous oxide emissions (SCN20). We performed a similar analysis to what is outlined above, and also noticed that these models are quite sensitive to assumptions. In particular, changes to the discount rate as well as the ECS distribution can result in reductions of the

Outdated Roe-Baker (2007) and More Recent ECS Distributions



SOURCES: Gerard H. Roe and Marcia B. Baker, "Why Is Climate Sensitivity So Unpredictable?" *Science*, Vol. 318, No. 5850 (October 26, 2007), pp. 629–632; Nicholas Lewis, "An Objective Bayesian Improved Approach for Applying Optimal Fingerprint Techniques to Estimate Climate Sensitivity," *Journal of Climate*, Vol. 26, No. 19 (October 2013), pp. 7414–7429; and Alexander Otto et al., "Energy Budget Constraints on Climate Response," *Nature Geoscience*, Vol. 6, No. 6 (June 2013), pp. 415–416; Nicholas Lewis and Judith A. Curry, "The Implications for Climate Sensitivity of AR5 Forcing and Heat Uptake Estimates," *Climate Dynamics*, Vol. 45, Issue 3, pp 1009-1923, http://link.springer.com/article/10.1007/s00382-014-2342-y (accessed February 27, 2017).

SCM and SCN20 by up to 80 percent. Thus, these models, like the SCC models, can also be effortlessly manipulated by user-selected assumptions.[13]

Negligible Environmental Benefits

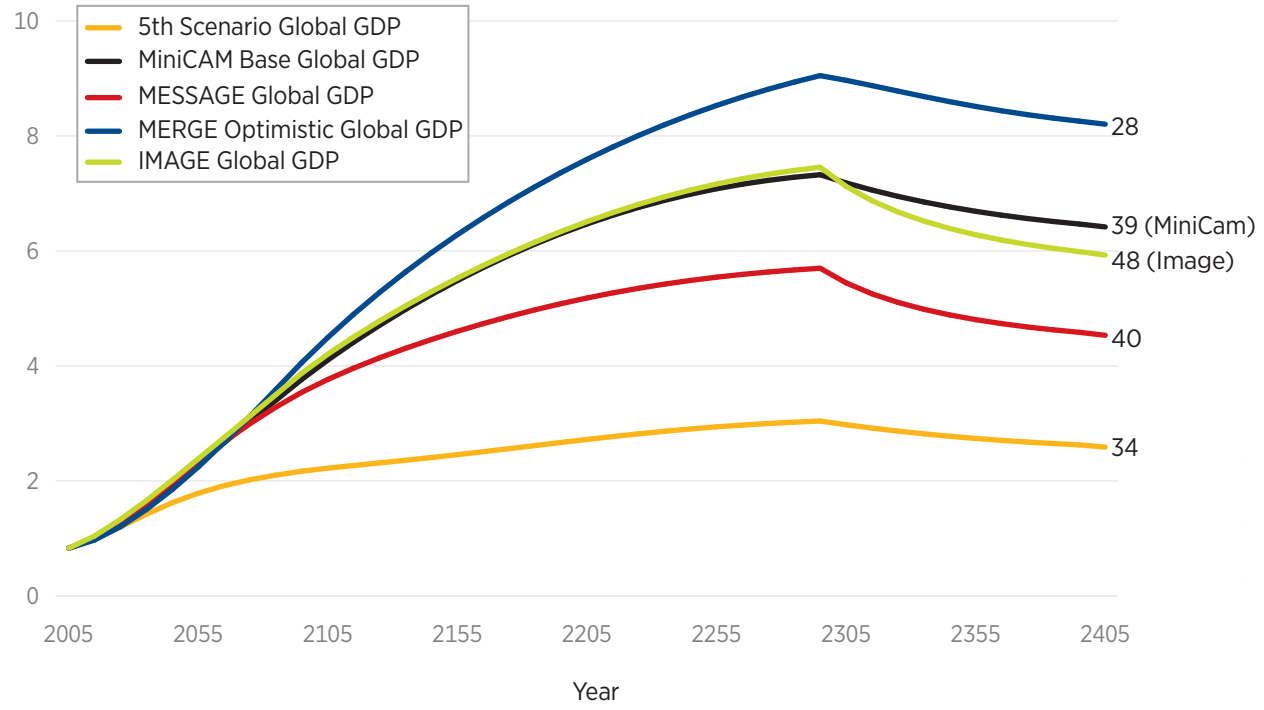
Given the sensitivity of these models to quite reasonable changes to assumptions, there is no reason to take them seriously for the purposes of policymaking. Regardless, we estimated the environmental impact of the associated regulations using the Model for the Assessment of Greenhouse Gas Induced Climate Change, and we simulated the environmental impact of eliminating greenhouse gas emissions from the United States completely. Even assuming a climate far more sensitive than the indefensible specifications made by the IWG in its analysis, simulation results indicate that if all carbon dioxide, methane, and nitrous oxide emissions were to be eliminated from the United States completely, the result in terms of temperature reductions would be less than 0.2 degrees C, 0.03 degrees C, and 0.02 degrees C, respectively. These temperature reductions would also be accompanied by miniscule changes in sea level rise (less than 2 centimeter reduction).[14]

Economic Consequences

On top of the aforementioned negligible environmental benefits, our research at Heritage has demonstrated that if the greenhouse gas regulations associated with these integrated models were actually implemented, the country would suffer disastrous economic consequences. Most notably, by 2035, the country would experience an average employment shortfall of 400,000 lost jobs, a total loss of income of over $20,000 for a family of four, a 13 percent to 20 percent increase in electricity prices, and an aggregate $2.5

Temperature Change (DICE)

FUTURE TEMPERATURE CHANGES (IN DEGREES CELSIUS)



NOTE: The 2020 value of the SCC (in $2007) produced by the DICE model (assuming a 3% discount rate) is included on the right-hand side of the figure.
SOURCE: Patrick J. Michaels, "An Analysis of the Obama Administration's Social Cost of Carbon," testimony before the Committee on Natural Resources, U.S. House of Representatives, July 22, 2015, https://www.cato.org/publications/testimony/analysis-obama-administrations-social-cost-carbon (accessed February 27, 2017).

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trillion loss in GDP. We have published other research in previous years, and they have also illustrated similar devastating consequences. On the other hand, taking advantage of the vast carbon-related sources of energy, such as shale oil and gas, will have essentially the opposite effect on the country—growing the economy, increasing household incomes, and adding hundreds of thousands of jobs for years to come.[15]

Criticisms

Critics may argue that the SCC has been underreported by the IWG. Much of this research, however, still suffers from many of the flaws discussed above. Furthermore, there are also questions regarding the legitimacy of the research that these studies are based on. Moore and Diaz (2015), for example, base their research on statistically insignificant results regarding the relationship between climate change and economic growth.

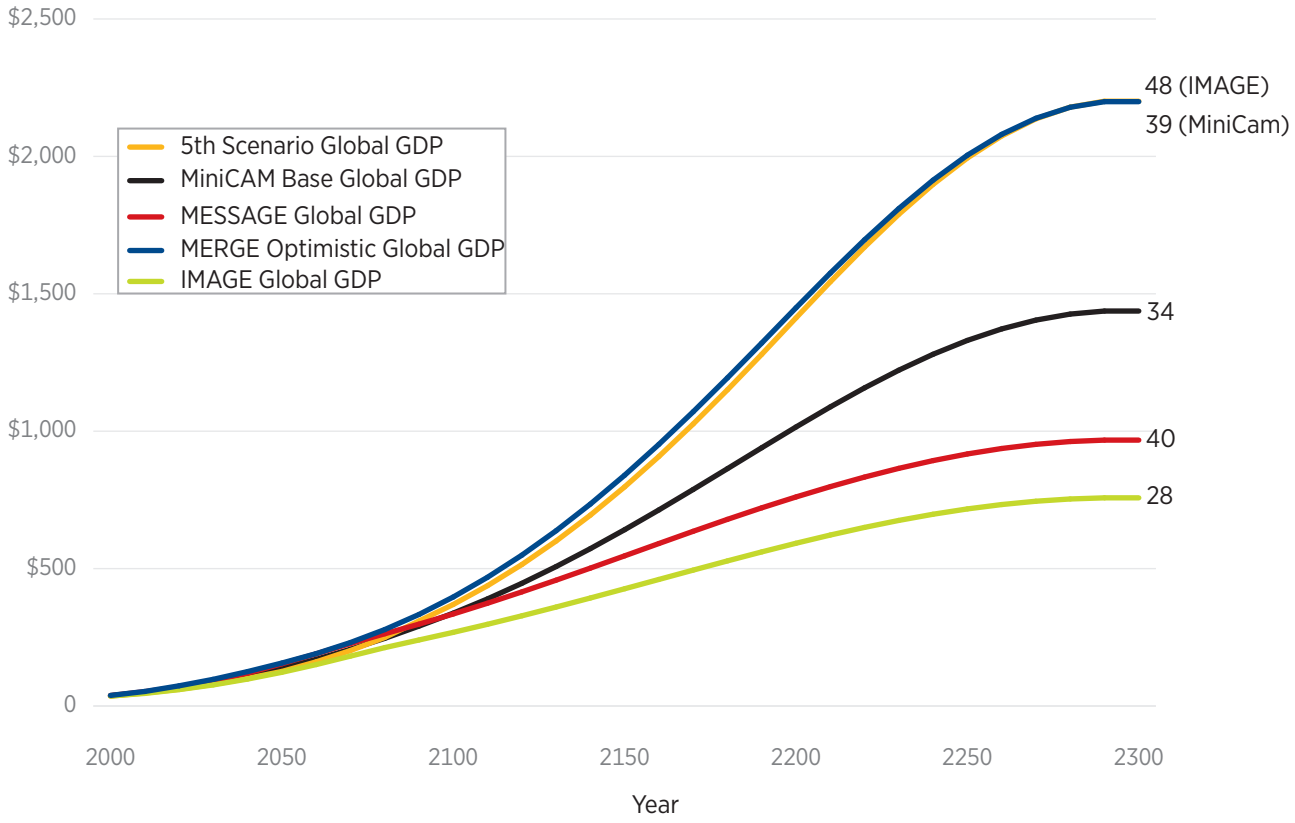
Altogether, there have in fact been nearly a thousand different estimates of the SCC, with results literally all across the map. Havernek et al. (2015) provides a nice summary of these estimates and finds that the IWG's reported results are higher than what the overall peer-reviewed literatures suggest.[16]

Conclusions

The SCC (as well as the SCM and SCN20) are based on statistical models that are extremely sensitive to important assumptions incorporated within the models. The climate sensitivity specifications the models make are outdated. Moreover, the damage functions that the estimates are based on are essentially arbitrary with limited empirical

Global GDP (DICE)

FUTURE GLOBAL GROSS DOMESTIC PRODUCT (IN BILLIONS OF DOLLARS).



NOTE: The 2020 value of the SCC (in $2007) produced by the DICE model (assuming a 3% discount rate) is included on the right-hand side of the figure.
SOURCE: Patrick J. Michaels, "An Analysis of the Obama Administration's Social Cost of Carbon," testimony before the Committee on Natural Resources, U.S. House of Representatives, July 22, 2015, https://www.cato.org/publications/testimony/analysis-obama-administrations-social-cost-carbon (accessed February 27, 2017).

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justification. Even if one were to take their results seriously, their use would result in significant economic damages with little benefit to reducing global temperatures. As a result, these models, although they may be interesting academic exercises, are far too unreliable for use in energy policy rulemaking and can be quite easily manipulated by user-selected assumptions. We thus urge policymakers to refrain from using them in devising regulatory policy.

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Endnotes

1. The official definition of the social cost of carbon is the economic damages per metric ton of CO_2 emissions, and is discussed further in U.S. Environmental Protection Agency, "The Social Cost of Carbon," http://www.epa.gov/climatechange/EPAactivities/economics/scc.html (accessed September 14, 2013).
2. For the DICE model, see William D. Nordhaus, "RICE and DICE Models of Economics of Climate Change," Yale University, November 2006, http://www.econ.yale.edu/~nordhaus/homepage/dicemodels.htm (accessed November 6, 2013). For the FUND model, see "FUND—Climate Framework for Uncertainty, Negotiation and Distribution," http://www.fund-model.org/ (accessed November 6, 2013). For the PAGE model, see Climate CoLab, "PAGE," http://climatecolab.org/resources/-/wiki/Main/PAGE (accessed November 6, 2013). See also

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3. Kevin D. Dayaratna and David W. Kreutzer, "Unfounded FUND: Yet Another EPA Model Not Ready for the Big Game," Heritage Foundation *Backgrounder* No. 2897, April 29, 2014, http://www.heritage.org/research/reports/2014/04/unfounded-fund-yet-another-epa-model-not-ready-for-the-big-game; Kevin D. Dayaratna and David W. Kreutzer, "Loaded DICE: An EPA Model Not Ready for the Big Game," Heritage Foundation *Backgrounder* No. 2860, November 21, 2013, http://www.heritage.org/research/reports/2013/11/loaded-dice-an-epa-model-not-ready-for-the-big-game; and Kevin D. Dayaratna, and David Kreutzer, "Environment: Social Cost of Carbon Statistical Modeling Is Smoke and Mirrors," *Natural Gas & Electricity*, Vol. 30, No. 12 (2014), pp. 7–11;

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4. Office of Management and Budget, "Circular A-4," White House, https://obamawhitehouse.archives.gov/omb/circulars_a004_a-4/ (accessed February 22, 2017), and Paul C. "Chip" Knappenberger, "An Example of the Abuse of the Social Cost of Carbon," Cato-at-Liberty, http://www.cato.org/blog/example-abuse-social-cost-carbon (accessed September 14, 2013).
5. Dayaratna and Kreutzer, "Loaded DICE: An EPA Model Not Ready for the Big Game."
6. John R. Christy, testimony before the Committee on Science, Space & Technology, U.S. House of Representatives, February 2, 2016, and John R. Christy, "A Factual Look at the Relationship Between Climate and Weather," testimony before the Subcommittee on Environment, Committee on Natural Resources, U.S. House of Representatives, December 11, 2013.
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