Comment by:

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on the

Energy Conservation Program: Energy Conservation Standards for Manufactured Housing; Notice of proposed rulemaking and public meeting.

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Comment:

Summary

Our comment primarily concerns the Department of Energy's (DOE) use of the social cost of carbon (SCC) in the cost/benefit analysis of the Energy Conservation Program: Energy Conservation Standards for Manufactured Housing proposed rulemaking. The DOE's determination of the SCC is discordant with the best scientific literature on the equilibrium climate sensitivity and the fertilization effect of carbon dioxide—two critically important parameters for establishing the net externality of carbon dioxide emissions. It is also at odds with existing Office of Management and Budget (OMB) guidelines for preparing regulatory analyses. It is based upon the output of Integrated Assessment Models (IAMs) which have little utility because of their great uncertainties, including uncertainties within the critical physical parameters upon which their simplified climate model are built. They provide no reliable guidance as to the sign, much less the magnitude of the social cost of carbon. Additionally, as run by the Interagency Working Group (IWG) (whose results were incorporated by the DOE in this action), the IAMs produce illogical results that indicate a misleading disconnection between climate changes and the SCC value. Further, we show that the sea level rise projections (and

thus SCC) of at least one of the IAMs (DICE 2010) is not supported by the mainstream climate science.

Until this entire situation can be properly rectified, the SCC should be barred from use in this and all other federal rulemaking. It is better not to include any value for the SCC in cost/benefit analyses such as these, than to include a value which is knowingly improper, inaccurate and misleading.

Discussion and Analysis

In the proposed rulemaking, the DOE recognizes that the determination of the SCC is rapidly evolving and dependent on the latest scientific findings. The DOE states that:

> DOE is well aware that scientific and economic knowledge about the contribution of CO_2 and other GHG emissions to changes in the future global climate and the potential resulting damages to the world economy continues to evolve rapidly. Thus, any value placed in this proposed rulemaking on reducing CO_2 emissions is subject to change. DOE, together with other federal agencies, will continue to review various methodologies for estimating the monetary value of reductions in CO_2 and other GHG emissions. This ongoing review will consider any comments on this subject that are part of the public record for this and other rulemakings, as well as other methodological assumptions and issues. However, consistent with DOE's legal obligations, and taking into account the uncertainty involved with this particular issue, DOE has included in this proposed rulemaking the most recent values and analyses resulting from the ongoing interagency review process.

In light of the DOE's and other federal agencies' on-going examination of the SCC we submit our comments for consideration on this topic. We note, however, that the May 2013 update (and subsequent July 2015 revision) to the SCC made by the Interagency Working Group (IWG) disregarded or ignored such a large amount of new evidence (extant at the time of the update), that the new SCC be considered invalid and discarded. It is better not to include any value for the SCC in federal cost/benefit analyses such as this one, than to include one which is knowingly inaccurate and thus potentially misleading.

Domestic vs. Global Costs

During the public comment period associated with new regulations such as this one which incorporate the SCC, a clear distinction should be made between domestic costs/benefits and foreign cost/benefits—and numerical calculations of each provided in all cost/benefits analyses included in the proposal *and to be included in the main body of the proposal*—such that the public can readily judge for itself the value of the regulation. As it currently stands, the public likely has little idea as to how large a percentage of the benefits of the proposed EPA regulations on *domestic* activities are conferred upon *foreign* nations under the guise of the SCC as the cost/benefit analysis results employing the domestic SCC are found only in the Technical Support Document accompanying this proposed regulation. We recommend reporting the results of the domestic SCC calculation in the main body of the proposed regulation. As it stands presently, the situation is clearly not as "transparent" as it could be,

Discount Rates

The Interagency Working group, in developing its SCC values ignores OMB guidelines in its selection of discount rates. OMB Circular A-4 refers to OMB Circular A-94 which states that "a real discount rate of 7 percent should be used as a base-case for regulatory analysis" and to show the sensitivity of the results to the discount rate assumptions "[f]or regulatory analysis, you should provide estimates of net benefits using both 3 percent and 7 percent."

Instead, the IWG opted to determine the SCC using discount rates of 2.5, 3, and 5 percent, and did not include results for a 7 percent rate.

This has ramifications throughout the federal regulatory agencies. For example, in this proposed rulemaking, the DOE violates OMB guidelines on how to calculate costs and benefits and does *not* present the results of using a SCC with the recommended 7% discount rate. This casts doubt on the veracity and utility of the cost/benefit analysis.

Instead of violating OMB guidelines for preparing cost/benefit studies to be used in preparing regulatory analyses, the DOE should calculate the domestic SCC as well as the SCC value using a 7 percent discount rate. These calculations should be included in the regulatory analysis for this proposed rulemaking. Not to do so leads to confusion and undermines the applicability of OMB guidelines and recommendations.

Equilibrium Climate Sensitivity

In May 2013, the Interagency Working Group (IWG) produced an updated SCC value by applying updates to the underlying three Integrated Assessment Models (IAMs) used in its initial 2010 SCC determination, but did not update the equilibrium climate sensitivity (ECS) employed in the IAMs. This remained the case in the IWG's most recent (July 2015) update. Since January 1, 2011, at least 15 new studies and 22 experiments (involving more than 46 researchers) examining the ECS, each lowering the best estimate and tightening the error distribution about that estimate. Instead, the IWG wrote in its 2013 report: "It does not revisit other interagency modeling decisions (e.g., with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity)."

The earth's equilibrium climate sensitivity is defined in the Interagency Working Group on Social Cost of Carbon 2010 (hereafter, IWG2010) report as "the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm))" and is recognized as "a key input parameter" for the integrated assessment models used to determine the social cost of carbon.

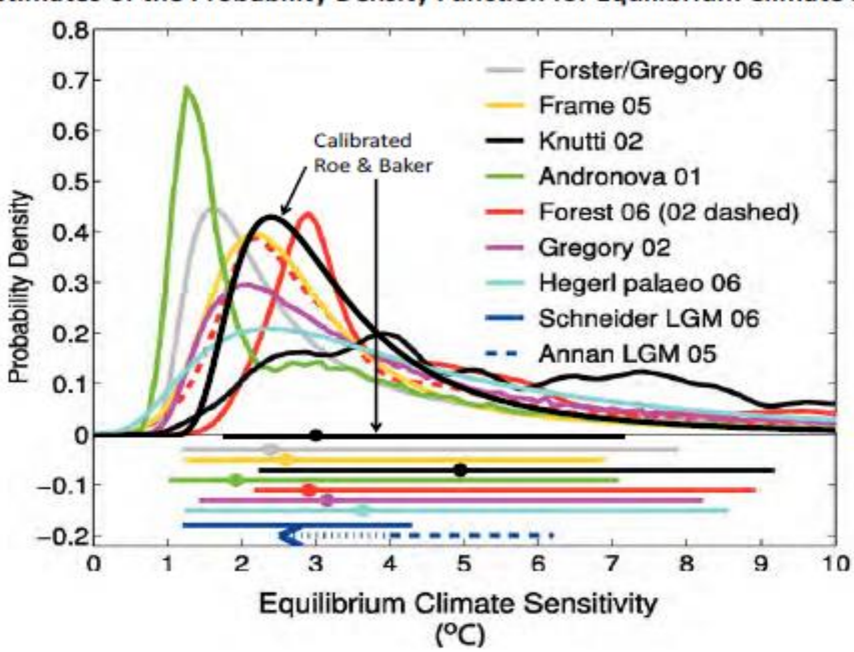
The IWG2010 report has an entire section (Section III.D) dedicated to describing how an estimate of the equilibrium climate sensitivity and the scientific uncertainties surrounding its actual value are developed and incorporated in the IWG's analysis. The IWG2010, in fact, developed its own probability density function (pdf) for the ECS and used it in each of the three IAMs, superseding the ECS pdfs used by the original IAMs developers. The IWG's intent was to develop an ECS pdf which most closely matched the description of the ECS as given in the *Fourth Assessment Report* of the United Nation's Intergovernmental panel on Climate Change which was published in 2007.

The functional form adopted by the IWG2010 was a calibrated version of Roe and Baker (2007) distribution. It was described in the IWG2010 report in the following Table and Figure (from the IWG2010 report):

Table 1: Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
10th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th percentile	5.86	5.14	4.93	4.69
95th percentile	7.14	5.97	5.59	5.17

Figure 2: Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)

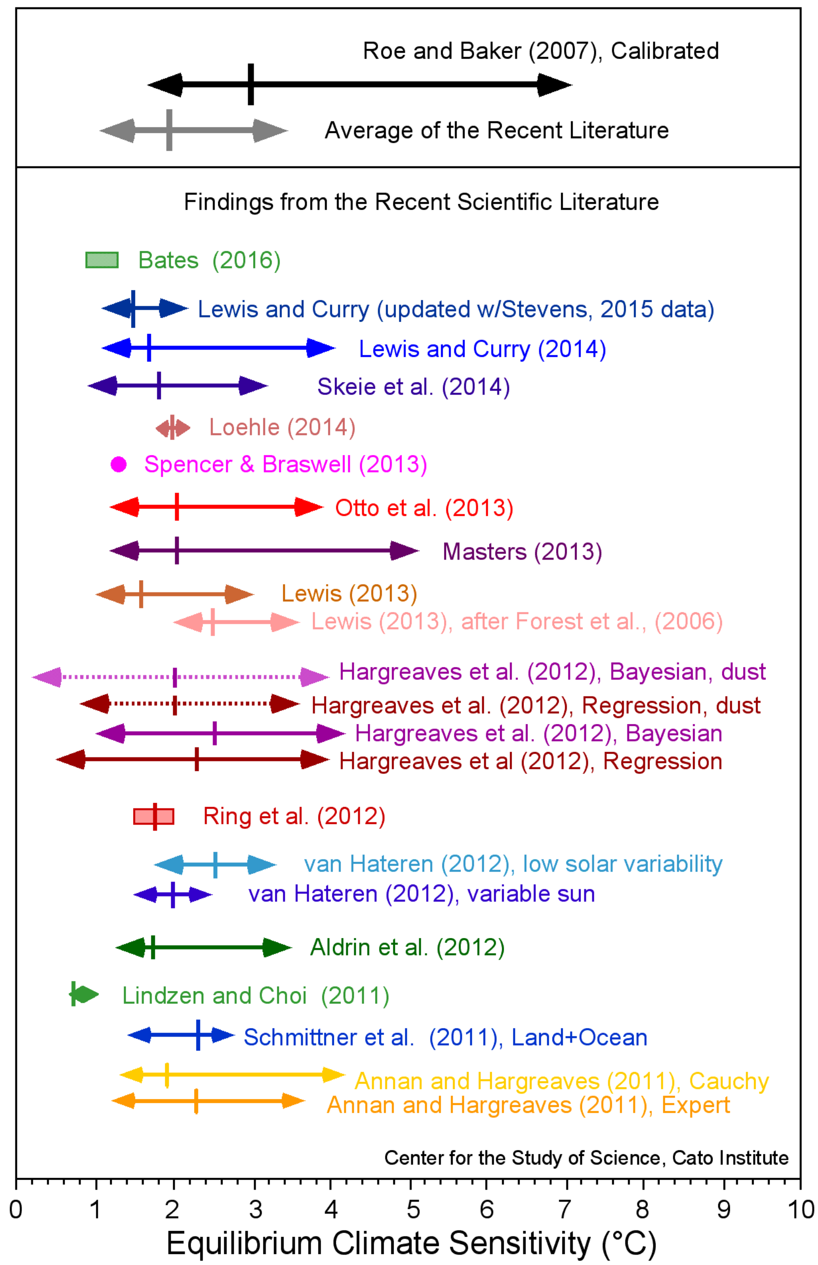


The calibrated Roe and Baker functional form used by the IWG2010 is *no longer scientifically defensible;* neither was it at the time of the publication of the IWG 2013 SCC update.

The figure below vividly illustrates this fact, as it compares the best estimate and 90% confidence range of the earth's ECS as used by the IWG2010/2013/2015 (calibrated Roe and Baker) against findings in the scientific literature published since January 1, 2011.

Whereas the IWG2010/2013/2015 ECS distribution has a median value of 3.0°C and 5^{th} and 95^{th} percentile values of 1.72°C and 7.14°C, respectively, the corresponding values averaged from the recent scientific literature are ~2.0°C (median), ~1.1°C (5^{th} percentile), and ~3.5°C (95^{th} percentile).

These differences will have large and significant impacts on the SCC determination.



CAPTION: The median (indicated by the small vertical line) and 90% confidence range (indicated by the horizontal line with arrowheads) of the climate sensitivity estimate used by the Interagency Working Group on the Social Cost of Carbon Climate (Roe and Baker, 2007) is indicated by the top black arrowed line. The average of the similar values from 20 different determinations reported in the recent scientific literature is given by the grey arrowed line (second line from the top). The sensitivity estimates from the 20 individual determinations of the ECS as reported in new research published after January 1, 2011 are indicated by the colored arrowed lines. The arrows indicate the 5 to 95% confidence bounds for each estimate along with the best estimate (median of each probability density function; or the mean of multiple estimates; colored vertical line). Ring et al. (2012) present four estimates of the climate sensitivity and the red box encompasses those estimates. Likewise, Bates (2016) presents eight estimates and the green box encompasses them. Spencer and Braswell (2013) produce a single ECS value best-matched to ocean heat content observations and internal radiative forcing.

In addition to recent studies aimed at directly determining the equilibrium climate sensitivity (included in the chart above), there have been several other major studies which have produced results which qualitatively suggest a climate sensitivity lower than mainstream (e.g. Roe and Baker calibration) estimates. Such studies include new insights on cloud condensation nuclei and cosmic rays (Kirkby et al., 2016), radiative forcing of clouds (Bellouin et al., 2016; Stevens, 2015), cloud processes (Mauritsen and Stevens, 2015) and the underestimation of terrestrial CO2 uptake (Sun et al., 2014).

The IWG2010 report noted that, concerning the low end of the ECS distribution, its determination reflected a greater degree of certainty that a low ECS value could be excluded than did the IPCC. From the IWG2010 (p. 14):

> "Finally, we note the IPCC judgment that the equilibrium climate sensitivity "is very likely larger than 1.5°C." Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5°C is almost 99 percent, is not inconsistent with the IPCC definition of "very likely" as "greater than 90 percent probability," it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC."

In other words, the IWG used its judgment that the lower bound of the ECS distribution was higher than the IPCC 2007 assessment indicated. However, the collection of the recent literature on the ECS shows the IWG's judgment to be in error. As can be seen in the chart above, the large majority of the findings on ECS in the recent literature indicate that the lower bound (i.e., 5^{th} percentile) of the ECS distribution is lower than the IPCC 2007 assessment. And, the average value of the 5^{th} percentile in the recent literature (~1.1°C) is 0.62°C less than that used by the IWG—a sizeable and important difference which will influence the SCC determination.

In fact, the abundance of literature supporting a lower climate sensitivity was at least partially reflected in the new IPCC assessment report issued in 2013. In that report, the IPCC reported:

> Equilibrium climate sensitivity is *likely* in the range 1.5°C to 4.5°C (*high confidence*), *extremely unlikely* less than 1°C (*high confidence*), and *very unlikely* greater than 6°C (*medium confidence*). The lower temperature limit of the assessed *likely* range is thus less than the 2°C in the AR4…

Clearly, the IWG's assessment of the low end of the probability density function that best describes the current level of scientific understanding of the climate sensitivity is incorrect and indefensible.

But even more influential in the SCC determination is the upper bound (i.e., 95^{th} percentile) of the ECS probability distribution.

The IWG2010 notes (p.14) that the calibrated Roe and Baker distribution better reflects the IPCC judgment that "values substantially higher than 4.5°C still cannot be excluded." The IWG2010 further notes that

> "Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95th percentiles of the three other calibrated distributions (5.2-6.0 °C)."

In other words, the IWG2010 turned towards surveys of the scientific literature to determine its assessment of an appropriate value for the 95th percentile of the ECS distribution. Now, more than three years hence, the scientific literature tells a completely different story.

Instead of a 95th percentile value of 7.14°C, as used by the IWG2010, a survey of the recent scientific literature suggests a value of ~3.5°C—more than 50% lower.

And this is very significant and important difference because the high end of the ECS distribution has a large impact on the SCC determination—a fact frequently commented on by the IWG2010.

For example, from IWG2010 (p.26):

> "As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change."

And further (p.30):

> *Uncertainty in extrapolation of damages to high temperatures*: The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (e.g., DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

And the entirety of Section V [sic] "A Further Discussion of Catastrophic Impacts and Damage Functions" of the IWG 2010 report describes "tipping points" and "damage functions" that are probabilities assigned to different values of global temperature change. Table 6 from the IWG2010 indicated the probabilities of various tipping points.

Table 6: Probabilities of Various Tipping Points from Expert Elicitation -

Possible Tipping Points	Duration before effect is fully realized (in years)	Additional Warming by 2100		
		0.5-1.5 C	1.5-3.0 C	3-5 C
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

The likelihood of occurrence of these low probability, high impact, events ("tipping points") is *greatly* diminished under the new ECS findings. The average 95th percentile value of the new literature survey is only ~3.5°C indicating a very low probability of a warming reaching 3-5°C by 2100 as indicated in the 3rd column of the above Table and thus a significantly lower probability that such tipping points will be reached. This new information will have a large impact on the final SCC determination using the IWG's methodology.

The size of this impact has been directly investigated.

In their Comment on the Landmark Legal Foundation Petition for Reconsideration of Final Rule Standards for Standby Mode and Off Mode Microwave Ovens, Dayaratna and Kreutzer (2013) ran the DICE model using the distribution of the ECS as described by Otto et al. (2013)—a paper published in the recent scientific literature which includes 17 authors, 15 of which were lead authors of chapters in the recent Intergovernmental Panel on Climate Change's *Fifth Assessment Report*. The most likely value of the ECS reported by Otto et al. (2013) was described as "2.0°C, with a 5–95% confidence interval of 1.2–3.9°C." Using the Otto et al. (2013) ECS distribution in lieu of the distribution employed by the IWG (2013), dropped the SCC by 42 percent, 41 percent, and 35 percent (for the 2.5%, 3.0%, 5.0% discount rates, accordingly). This is a significant decline.

In subsequent research, Dayaratna and Kreutzer (2014) examined the performance of the FUND model, and found that it too, produced a greatly diminished value for the SCC when run with the Otto et al. distribution of the equilibrium climate sensitivity. Using the Otto et al. (2013) ECS distribution in lieu of the distribution employed by the IWG (2013), dropped the SCC produced by the FUND model to $11, $6, $0 compared with the original $30, $17, $2 (for the 2.5%, 3.0%, 5.0% discount rates, accordingly). Again, this is a significant decline.

The Dayaratna and Kreutzer (2014) results using FUND were in line with alternative estimates of the impact of a lower climate sensitivity on the FUND model SCC determination.

Waldhoff et al. (2011) investigated the sensitivity of the FUND model to changes in the ECS. Waldhoff et al. (2011) found that changing the ECS distribution such that the mean of the distribution was lowered from 3.0°C to 2.0°C had the effect of lowering the SCC by 60 percent (from a 2010 SCC estimate of $8/ton of CO2 to $3/ton in $1995). While Waldhoff et al. (2011) examined FUNDv3.5, the response of the current version (v3.8) of the FUND model should be similar.

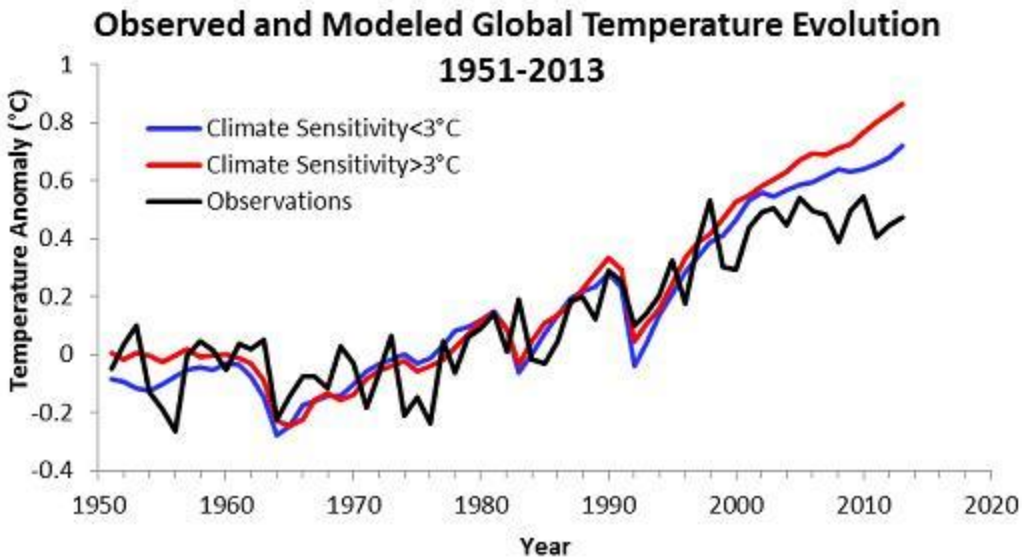
Additionally, the developer of the PAGES model, affirmed that the SCC from the PAGES model, too drops by 35% when the Otto et al. (2013) climate sensitivity distribution is employed (Hope, 2013).

More recently, the FUND and DICE model were run with equilibrium climate sensitivities that were determined by Lewis and Curry (2014) in an analysis which updated and expanded upon the results of Otto et al. (2013). In Dayaratna et al. (2016), the probability density function (pdf) for the equilibrium climate sensitivity determined from an energy budget model (Lewis and Curry, 2014) was used instead of the Roe and Baker calibrated pdf used by the IWG. In doing so, Dayaranta et al. (2016) report:

> "In the DICE model the average SCC falls by 30-50% depending on the discount rate, while in the FUND model the average SCC falls by over 80%. The span of estimates across discount rates also shrinks considerably, implying less sensitivity to this parameter choice…Furthermore the probability of a negative SCC (implying CO2 emissions are a positive externality) jumps dramatically using an empirical ECS distribution."

These studies make clear that the strong dependence of the social cost of carbon on the distribution of the estimates of the equilibrium climate sensitivity (including the median, and the upper and lower certainty bounds) requires that the periodic updates to the IWG SCC determination must include an examination of the scientific literature on the topic of the equilibrium climate sensitivity. There is no indication that the IWG undertook such an examination. But what is clear, is that the IWG did *not* alter its probability distribution of the ECS between its 2010 and 2015 SCC determination, despite a large and growing body of scientific literature that substantially alters and better defines the scientific understanding of the earth's ECS. It is unacceptable that a supposed "updated" social cost of carbon does not include updates to the science underlying a critical and key aspect of the SCC.

We note that there has been one prominent scientific study in the recent literature which has argued, on the basis of recent observations of lower tropospheric mixing in the tropics, for a rather high climate sensitivity (Sherwood et al., 2014). This research, however, suffers from too narrow a focus. While noting that climate models which best match the apparent observed behavior of the vertical mixing characteristics of the tropical troposphere tend to be the models with high climate sensitivity estimates, the authors fail to make note that these same models are the ones whose projections make the *worst* match to observations of the evolution of global temperature during the past several decades. The figure below shows the observed global surface temperature history from 1951-2013 compared with the temperature evolution projected by the collection of models used in the new IPCC 2013 report. We broke the climate models down into two groups—those which have a climate sensitivity greater than 3.0°C (as suggested by Sherwood et al., 2014) and those with a climate sensitivity less than 3.0°C. The Figure shows that while neither model subset does a very good job is capturing evolution of global temperature during the past 15-20 years (the period with the highest human carbon dioxide emissions), the high sensitivity models do substantially worse than the lower sensitivity models.

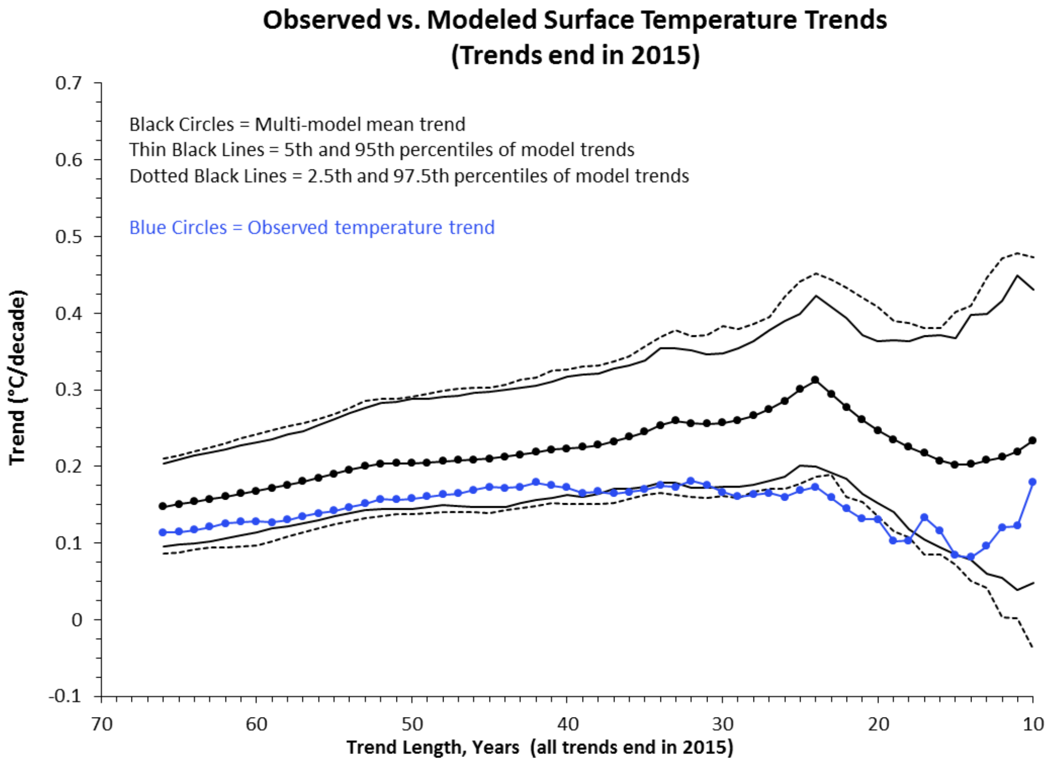


CAPTION: Observed global average temperature evolution, 1951-2013, as compiled by the U.K's Hadley Center (black line), and the average temperature change projected by a collection of climate models used in the IPCC Fifth Assessment Report which have a climate sensitivity greater than 3.0°C (red line) and a collection of models with climate sensitivities less than 3.0°C (blue line).

While Sherwood et al. (2014) prefer models that better match their observations in one variable, the same models actually do *worse* in the big picture than do models which lack the apparent accuracy in the processes that Sherwood et al. (2014) describe. The result can only mean that there must still be even bigger problems with *other* model processes which must more than counteract the effects of the processes described by Sherwood et al. After all, the overall model collective is still warming the world much faster than it actually is (see Figure below). In fact, the observed global average temperature evolution for much of the past 66 years lies in the lower half of the range which encompasses all climate model runs, and during some period, it lies outside of the range including 95% of model runs—an indication that the observed trend is statistically different from the trend simulated by climate models.

We note that our statistics are based upon both the warm and the cold departures from predicted trends. In reality, the cold departure is what is of most interest from a policy perspective—for if warming is being demonstrably overpredicted, then policies based upon models that are in error are a substantial regulatory overreach. Our probability estimates are conservative as values at the .05 level are actually at the 2.5th percentile for warmth from the model ensemble.

These results argue strongly against the reliability of the Sherwood et al. (2014) conclusion and instead provide robust observational evidence that the climate sensitivity has been overestimated by both climate models, and the IWG alike.



CAPTION: The annual average global surface temperature from 108 individual CMIP5 climate model runs forced with historical (+ RCP45 since 2006) forcings were obtained from the Climate Explorer website. Linear trends were computed through the global temperatures from each run, ending in 2015 and beginning each year from 1951 through 2006. The trends for each period (ranging in length from 10 to 65 years) were averaged across all model runs (black dots). The range containing 90 percent (thin black lines), and 95 percent (dotted black lines) of trends from the 108 model runs is also indicated. The observed linear trends for the same periods were calculated from the annual average global surface temperature record compiled by the U.K. Hadley Center (HadCRUT4) (blue dots).

Agricultural Impacts of Carbon Fertilization

Carbon dioxide is known to have a large positive impact on vegetation (e.g., Zhu et al., 2016), with literally thousands of studies in the scientific literature demonstrating that plants (including crops) grow stronger, healthier, and more productive under conditions of increased carbon dioxide concentration. A recent study (Idso, 2013) reviewed a large collection of such literature as it applies to the world's 45 most important food crops (making up 95% of the world's annual agricultural production).

Idso (2013) summarized his findings on the increase in biomass of each crop that results from a 300ppm increase in the concentration of carbon dioxide under which the plants were grown. This table is reproduced below, and shows that the typical growth increase exceeds 30% in most crops, including 8 of the world's top 10 food crops (the increase was 24% and 14% in the other two).

Average percentage increase in biomass of each of the world's 45 most important food crops under an increase of 300ppm of carbon dioxide.

Crop	% Biomass Change	Crop	% Biomass Change
Sugar cane	34.0%	Rye	38.0%
Wheat	34.9%	Plantains	44.8%
Maize	24.1%	Yams	47.0%
Rice, paddy	36.1%	Groundnuts, with shell	47.0%
Potatoes	31.3%	Rapeseed	46.9%
Sugar beet	65.7%	Cucumbers and gherkins	44.8%
Cassava	13.8%	Mangoes, mangosteens, guavas	36.0%
Barley	35.4%	Sunflower seed	36.5%
Vegetables fresh nes	41.1%	Eggplants (aubergines)	41.0%
Sweet potatoes	33.7%	Beans, dry	61.7%
Soybeans	45.5%	Fruit Fresh Nes	72.3%
Tomatoes	35.9%	Carrots and turnips	77.8%
Grapes	68.2%	Other melons (inc.cantaloupes)	4.7%
Sorghum	19.9%	Chillies and peppers, green	41.1%
Bananas	44.8%	Tangerines, mandarins, clem.	29.5%
Watermelons	41.5%	Lettuce and chicory	18.5%
Oranges	54.9%	Pumpkins, squash and gourds	41.5%
Cabbages and other brassicas	39.3%	Pears	44.8%
Apples	44.8%	Olives	35.2%
Coconuts	44.8%	Pineapples	5.0%
Oats	34.8%	Fruit, tropical fresh nes	72.3%
Onions, dry	20.0%	Peas, dry	29.2%
Millet	44.3%		

Idso (2013) found that the increase in the atmospheric concentration of carbon dioxide that took place during the period 1961-2011 was responsible for increasing global agricultural output by 3.2 trillion dollars (in 2004-2006 constant dollars). Projecting the increases forward based on projections of the increase in atmospheric carbon dioxide concentration, Idso (2013) expects carbon dioxide fertilization to increase the value of agricultural output by 9.8 trillion dollars (in 2004-2006 constant dollars) during the 2012-2050 period.

This is a large positive externality, and one that is insufficiently modeled in the IAMs relied upon by the IWG in determining the SCC.

In fact, only one of the three IAMs used by the IWG has any substantial impact from carbon dioxide fertilization despite the DOE's contention in this NOPR that the SCC is intended to reflect impacts on agriculture (e.g., "[The SCC] is intended to include (but is not limited to) changes in net agricultural productivity"). And the one IAM that does (FUND), underestimates the effect by approximately 2-3 times.

The FUND model has a component which calculates the impact on agricultural as a result of carbon dioxide emissions, which includes not only the impact on temperature and other climate changes, but also the direct impact of carbon dioxide fertilization. The other two IAMs, DICE and PAGE by and large do not (or only do so extremely minimally; DICE includes the effect to a larger degree than PAGE). Consequently, lacking this large and positive externality, the SCC calculated by the DICE and PAGE models is significantly larger than the SCC determined by the FUND model (for example, see Table A5, in the IWG 2013 report).

But even the positive externality that results from carbon dioxide fertilization as included in the FUND model is too small when compared with the Idso (2013) estimates. FUND (v3.7) uses the following formula to determine the degree of crop production increase resulting from atmospheric carbon dioxide increases (taken from Anthoff and Tol, 2013a):

> CO_2 fertilisation has a positive, but saturating effect on agriculture, specified by
>
> (A.4) $$A^f_{t,r} = \gamma_r \ln \frac{CO2_t}{275}$$
>
> where
>
> - A^f denotes damage in agricultural production as a fraction due to the CO2 fertilisation by time and region;
> - t denotes time;
> - r denotes region;
> - $CO2$ denotes the atmospheric concentration of carbon dioxide (in parts per million by volume);
> - 275 ppm is the pre-industrial concentration;
> - γ is a parameter (see Table A, column 8-9).

Column 8 in the table below shows the CO_2 fertilization parameter (γ_r) used in FUND for various regions of the world (Anthoff and Tol, 2013b). The average CO_2 fertilization effect across the 16 regions of the world is 11.2%. While this number is neither areally weighted, nor weighted by the specific crops grown, it is clear that 11.2% is much lower than the average fertilization effect compiled by Idso (2013) for the world's top 10 food crops (35%). Further, Idso's fertilization impact is in response to a 300ppm CO2 increase, while the fertilization parameter in the FUND model is multiplied by $\ln(CO2_t/275)$ which works out to 0.74 for a 300ppm CO_2 increase. This multiplier further reduces the 16 region average to 8.4% for the CO_2 fertilization effect—some 4 times smaller than the magnitude of the fertilization impact identified by Idso (2013).

Impact of climate change on agriculture in FUND model.

	Rate of change (% Ag. Prod/ 0.04°C)		δ_r^l		δ_r^q		CO_2 fertilisation (% Ag. Prod)	
USA	-0.021	(0.176)	0.026	(0.021)	-0.012	(0.018)	8.90	(14.84)
CAN	-0.029	(0.073)	0.092	(0.080)	-0.016	(0.009)	4.02	(6.50)
WEU	-0.039	(0.138)	0.022	(0.002)	-0.014	(0.013)	15.41	(11.83)
JPK	-0.033	(0.432)	0.046	(0.022)	-0.024	(0.030)	23.19	(36.60)
ANZ	-0.015	(0.142)	0.040	(0.071)	-0.016	(0.037)	10.48	(8.50)
EEU	-0.027	(0.062)	0.048	(0.097)	-0.018	(0.048)	9.52	(5.14)
FSU	-0.018	(0.066)	0.042	(0.075)	-0.016	(0.039)	6.71	(5.48)
MDE	-0.022	(0.032)	0.042	(0.071)	-0.017	(0.037)	9.43	(2.66)
CAM	-0.034	(0.061)	0.064	(0.043)	-0.030	(0.043)	16.41	(5.38)
SAM	-0.009	(0.060)	0.003	(0.005)	-0.004	(0.003)	5.96	(5.04)
SAS	-0.014	(0.021)	0.025	(0.024)	-0.011	(0.018)	5.80	(1.64)
SEA	-0.009	(0.482)	0.014	(0.004)	-0.010	(0.008)	8.45	(41.81)
CHI	-0.013	(0.075)	0.043	(0.076)	-0.017	(0.040)	19.21	(6.13)
NAF	-0.016	(0.023)	0.033	(0.043)	-0.014	(0.027)	7.27	(1.90)
SSA	-0.011	(0.026)	0.024	(0.034)	-0.010	(0.020)	5.05	(2.20)
SIS	-0.050	(0.103)	0.043	(0.077)	-0.017	(0.040)	23.77	(8.64)

Standard deviations are given in brackets.

Although approximately four times too small, the impact of the fertilization effect on the SCC calculation in the FUND model is large.

According to Waldhoff et al. (2011), if the CO_2 fertilization effect is turned off in the FUND model (v3.5) the SCC increases by 75% from \$8/tonCO_2 to \$14/tonCO_2 (in 1995 dollars). In another study, Ackerman and Munitz (2012) find the effective increase in the FUND model to be even larger, with CO_2 fertilization producing a positive externality of nearly \$15/tonCO_2 (in 2007 dollars).

Clearly, had the Idso (2013) estimate of the CO_2 fertilization impact been used instead of the one used in FUND the resulting positive externality would have been much larger, and the resulting net SCC been much lower.

This is just for one of the three IAMs used by the IWG. Had the more comprehensive CO_2 fertilization impacts identified by Idso (2013) been incorporated in all the IAMs, the three-model average SCC used by the IWG would be been greatly lowered, and likely even become negative in some IAM/discount rate combinations.

Additional Climate Model Parameter Misspecifications

In addition to the outdated climate sensitivity distribution and the insufficient handling of the carbon dioxide fertilization effect, there has also been identified a misspecification of some of the critical parameters within the underlying box models that drive the pace and shape of the future climate evolution in the IAMs.

A recent analysis (Lewis, 2016) finds that the physically-based two-box climate model inherent in the DICE IAM is fit with physically unrealistic ocean characteristics. According to Lewis (2016):

> In the DICE 2-box model, the ocean surface layer that is taken to be continuously in equilibrium with the atmosphere is 550 m deep, compared to estimates in the range 50–150 m based on observations and on fitting 2-box models to AOGCM responses. The DICE 2-box model's deep ocean layer is less than 200 m deep, a fraction of the value in any CMIP5 AOGCM, and is much more weakly coupled to the surface layer. Unsurprisingly, such parameter choices produce a temperature response time profile that differs substantially from those in AOGCMs and in 2-box models with typical parameter values. As a result, DICE significantly overestimates temperatures from the mid-21st century on, and hence overestimates the SCC and optimum carbon tax, compared with 2-box models having the same ECS and TCR but parameter values that produce an AOGCM-like temperature evolution.

When the DICE 2-box model is parametrized with values for the ocean layers that are in line with established estimates, the value of the social cost of carbon that results is reduced by one-quarter to one-third during the 21th century. Lewis further point out that notes that "The climate response profile in FUND and in PAGE, the other two IAMs used by the US government to assess the SCC, appear to be similarly inappropriate, suggesting that they also overestimate the SCC."

Ultimately, Lewis (2016) concludes:

> It seems rather surprising that all three of the main IAMs have climate response functions with inappropriate, physically unrealistic, time profiles. In any event, it is worrying that governments and their scientific and economic advisers have used these IAMs and, despite considering what [equilibrium climate sensitivity] and/or [transient climate sensitivty] values or probability distributions thereof to use, have apparently not checked whether the time profiles of the resulting climate responses were reasonable.

The Misleading Disconnect Between Climate Change and the Social Cost of Carbon in the Integrated Assessment Models

It is generally acknowledged, the results from IAMs are highly sensitive not only to the model input parameters but also to how the models have been developed and what processes they try to include. One prominent economist, Robert Pindyck of M.I.T. recently wrote (Pindyck, 2013) that the sensitivity of the IAMs to these factors renders them useless in a policymaking environment:

> 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.

Nevertheless, DOE has incorporated the IWG2013 determinations of the SCC into the cost/benefit analysis of this proposed regulation—ill-advisedly so in our opinion.

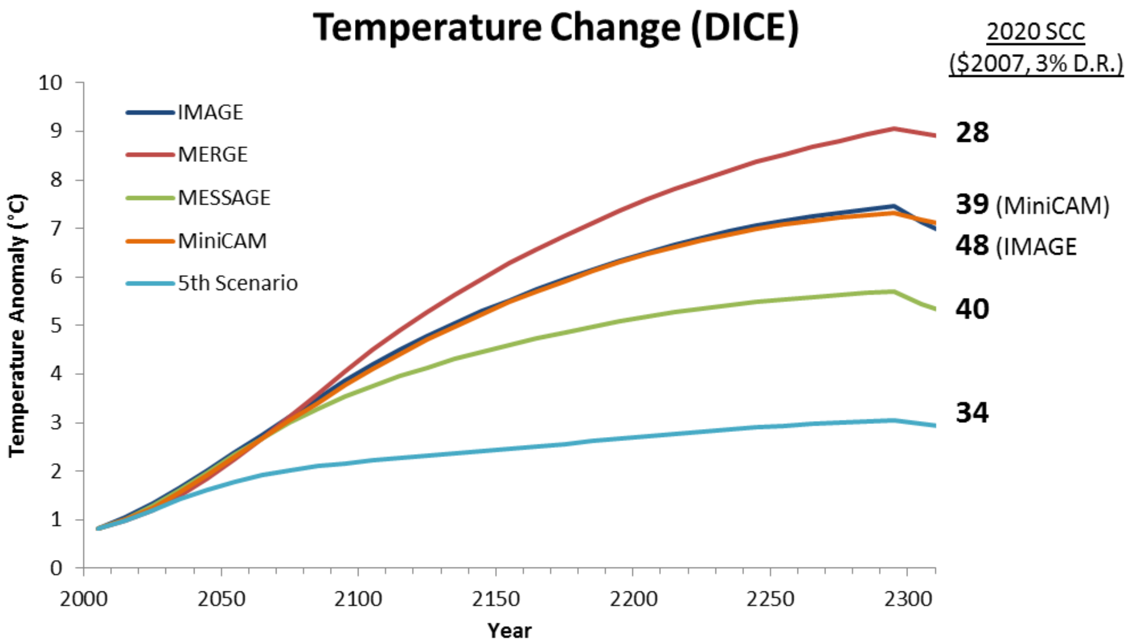
Consider the following: the social cost of carbon should reflect the relative impact on future society that human-induced climate change from greenhouse gas emissions would impose. In this way, we can decide how much (if at all) we are willing to pay currently to reduce the costs to future society. It would seem logical that we would probably be more willing to sacrifice more now if we knew that future society would be impoverished and suffer from extreme climate change than we would be willing to sacrifice if we knew that future society would be very well off and be subject to more moderate climate change. We would expect that the value of the social cost of carbon would reflect the difference between these two hypothetical future worlds—the SCC should be far greater in an impoverished future facing a high degree of climate change than an affluent future with less climate change.

But if you thought this, you would be wrong.

Instead, the IAMs as run by the IWG2013 produce nearly the opposite result—the SCC is far *lower* in the less affluent/high climate change future than it is in the more affluent/low climate change future. Such a result is not only counterintuitive but misleading.

We illustrate this illogical and impractical result using the DICE 2010 model (hereafter just DICE) used by the IWG2013 (although the PAGE and the FUND models generally show the same behavior). The DICE model was installed and run at the Heritage Foundation by Kevin Dayaratna and David Kreutzer using the same model set up and emissions scenarios as prescribed by the IWG2013. The projections of future temperature change (and sea level rise, used later in the Comment) were graciously provided to us by the Heritage Foundation.

The figure below shows the projections of the future change in the earth's average surface temperature for the years 2000-2300 produced by DICE from the five emissions scenarios employed by the IWG2013. The numerical values on the right-hand side of the illustration are the values for the social cost of carbon associated with the temperature change resulting from each emissions scenario (the SCC is reported for the year 2020 using constant $2007 and assuming a 3% discount rate—numbers taken directly from Table A3 of the IWG2013 report). The temperature change can be considered a good proxy for the magnitude of the overall climate change impacts.

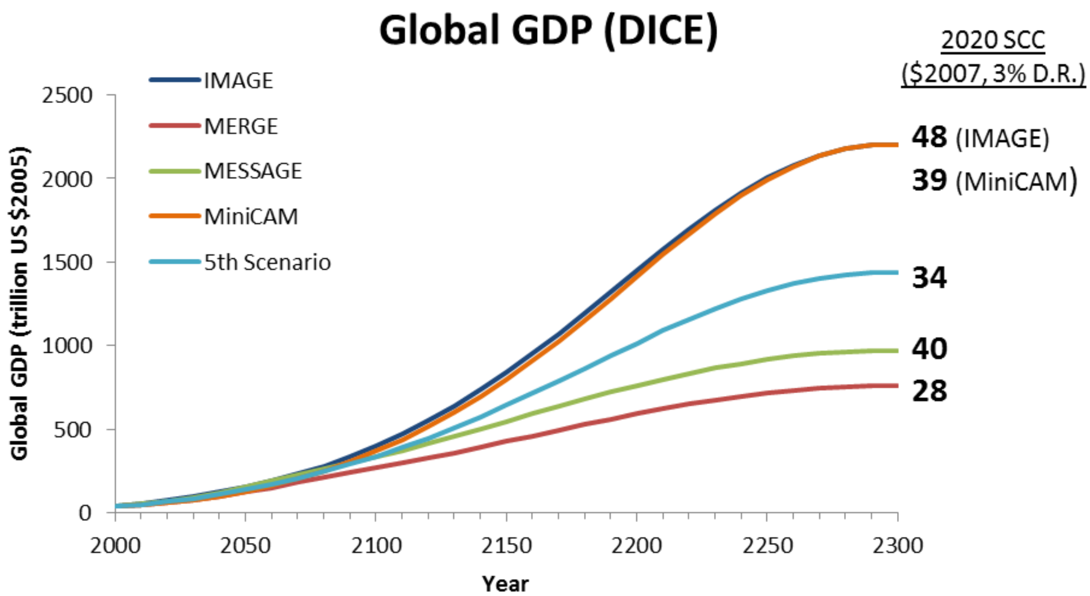


CAPTION: Future temperature changes, for the years 2000-2300, projected by the DICE model for each of the five emissions scenarios used by the IWG2013. The temperature changes are the arithmetic average of the 10,000 Monte Carlo runs from each scenario. The 2020 value of the SCC (in $2007) produced by the DICE model (assuming a 3% discount rate) is included on the right-hand side of the figure. (DICE data provided by Kevin Dayaratna and David Kreutzer of the Heritage Foundation).

Notice in the figure above that the value for the SCC shows little (if any) correspondence to the magnitude of climate change. The MERGE scenario produces the greatest climate change and yet has the smallest SCC associated with it. The "5th Scenario" is a scenario that attempts to keep the effective concentration of atmospheric carbon dioxide at 550 ppm (far lower than the other scenarios) has a SCC that is more than 20% *greater* than the MERGE scenario. The global temperature change by the year 2300 in the MERGE scenario is 9°C while in the "5th Scenario" it is only 3°C. The highest SCC is from the IMAGE scenario—a scenario with a mid-range climate change. All of this makes absolutely no logical sense—and confuses the user.

If the SCC bears little correspondence to the magnitude of future human-caused climate change, than what does it represent?

The figure below provides some insight.



CAPTION: Future global gross domestic product, for the years 2000-2300 for each of the five emissions scenarios used by the IWG2013. 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.

When comparing the future GDP to the SCC, we see, generally, that the scenarios with the higher future GDP (most affluent future society) have the higher SCC values, while the futures with lower GDP (less affluent society) have, generally, lower SCC values.

Combining the results from the two figures above thus illustrates the absurdities in the IWG's use of the DICE model. The scenario with the richest future society and a modest amount of climate change (IMAGE) has the highest value of the SCC associated with it, while the scenario with the poorest future society and the greatest degree of climate change (MERGE) has the lowest value of the SCC. A logical, thinking person would assume the opposite.

While we only directly analyzed output data from the DICE model, by comparing Tables 2 and Tables 3 from the IWG2010 report, it can be ascertained that the FUND and the PAGE models behave in a similar fashion.

This counterintuitive result occurs because the damage functions in the IAMs produce output in terms of a percentage decline in the GDP—which is then translated into a dollar amount (which is divided by the total carbon emissions) to produce the SCC. Thus, even a small climate change-induced percentage decline in a high GDP future yields greater dollar damages (i.e., higher SCC) than a much greater climate change-induced GDP percentage decline in a low GDP future.

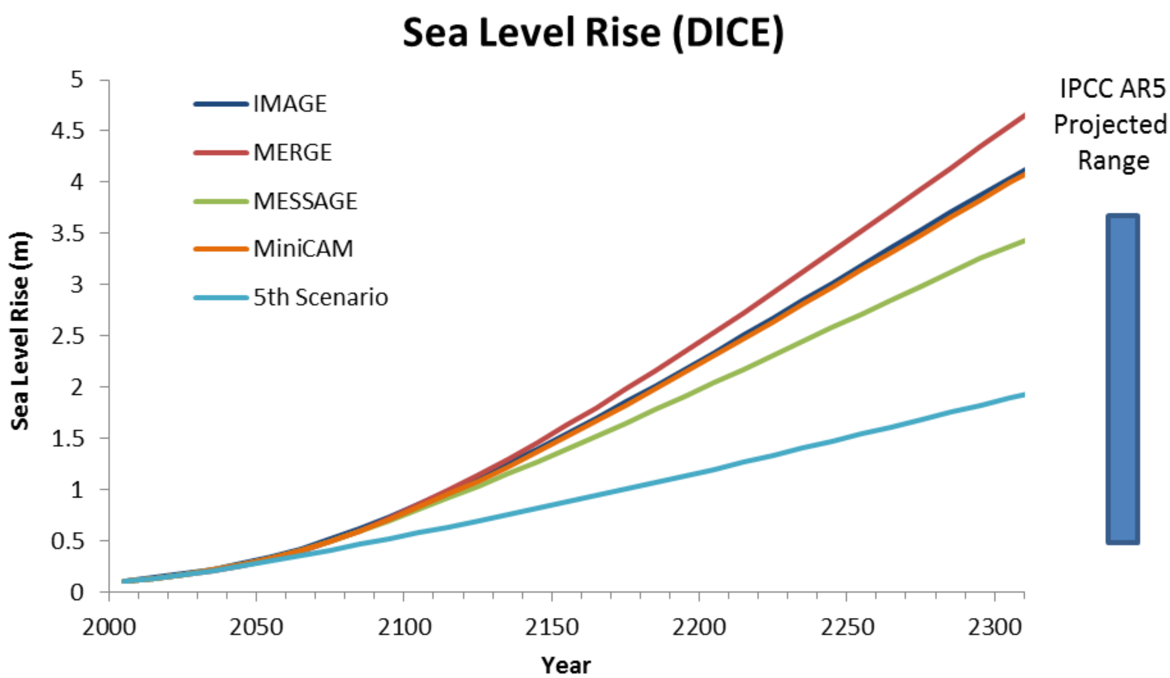
Who in their right mind would want to spend (sacrifice) more today to help our rich decedents deal with a lesser degree of climate change than would want to spend (sacrifice) today to help our relatively less-well-off decedents deal with a greater degree of climate change? No one. Yet that is what the SCC would lead you to believe and that is what the SCC implies when it is incorporated into federal cost/benefit analyses.

In principle, the way to handle this situation is by allowing the discount rate to change over time. In other words, the richer we think people will be in the future (say the year 2100), the higher the discount rate we should apply to damages (measured in 2100 dollars) they suffer from climate change, in order to decide how much we should be prepared to sacrifice today on their behalf.

Until (if ever) the current situation is properly rectified, the IWG's determination of the SCC is not fit for use in the federal regulatory process, such as this DOE regulation, as it is deceitful and misleading.

Sea Level Rise

The sea level rise module in the DICE model used by the IWG2013 produces future sea level rise values that far exceed mainstream projections and are unsupported by the best available science. The sea level rise projections from more than half of the scenarios (IMAGE, MERGE, MiniCAM) exceed even the highest end of the projected sea level rise by the year 2300 as reported in the *Fifth Assessment Report* (AR5) of the Intergovernmental Panel on Climate Change (see figure).



CAPTION: Projections of sea level rise from the DICE model (the arithmetic average of the 10,000 Monte Carlo runs from each scenario) for the five scenarios examined by the IWG2013 compared with the range of sea level rise projections for the year 2300 given in the IPCC AR5 (see AR5 Table 13.8). (DICE data provided by Kevin Dayaratna and David Kreutzer of the Heritage Foundation).

How the sea level rise module in DICE was constructed is inaccurately characterized by the IWG2013 (and misleads the reader). The IWG2013 report describes the development of the DICE sea level rise scenario as:

"The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC's Fourth Assessment Report (AR4).[6]"

However, in IWG2013 footnote "6" the methodology is described this way (Nordhaus, 2010):

> "The methodology of the modeling is to use the estimates in the IPCC Fourth Assessment Report (AR4)."

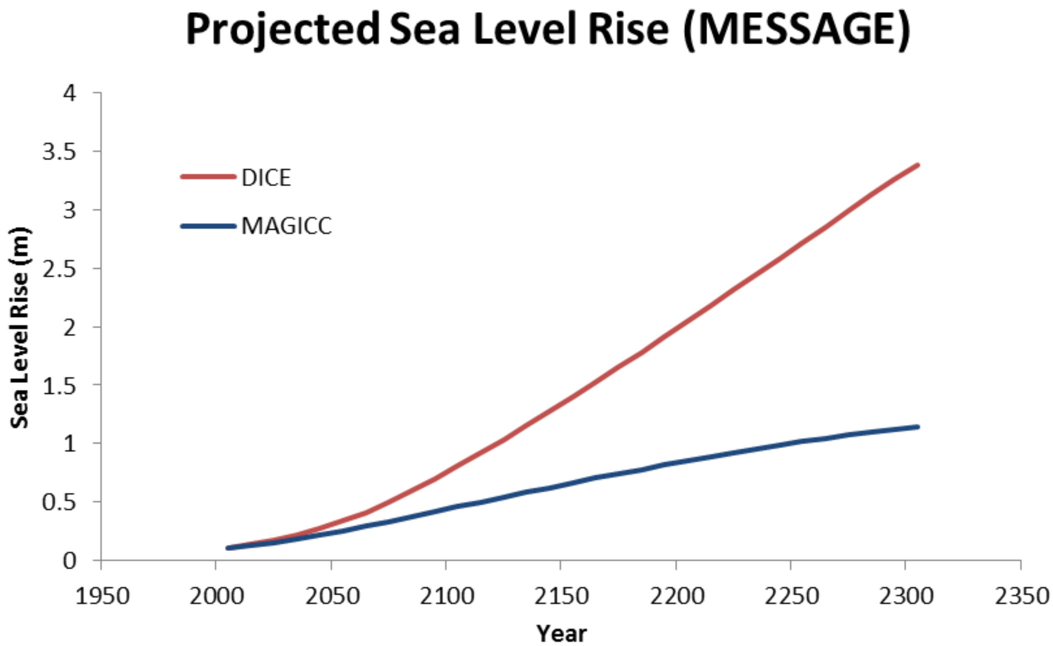
"Using estimates" and "calibrating" are two completely different things. Calibration implies that the sea level rise estimates produced by the DICE sea level module behave similarly to the IPCC sea level rise projections and instills a sense of confidence in the casual reader that the DICE projections are in accordance with IPCC projections. However this is not the case. Consequently, the reader is misled.

In fact, the DICE estimates are much higher than the IPCC estimates. This is even recognized by the DICE developers. From the same reference as above:

> "The RICE [DICE] model projection is in the middle of the pack of alternative specifications of the different Rahmstorf specifications. Table 1 shows the RICE, base Rahmstorf, and average Rahmstorf. *Note that in all cases, these are significantly above the IPCC projections in AR4.*" [emphasis added]

That the DICE sea level rise projections are far above the mainstream estimated can be further evidenced by comparing them with the results produced by the IWG-accepted MAGICC modelling tool (in part developed by the EPA and available from http://www.cgd.ucar.edu/cas/wigley/magicc/).

Using the MESSAGE scenario as an example, the sea level rise estimate produced by MAGICC for the year 2300 is 1.28 meters—a value that is less than 40% of the average value of 3.32 meters produced by the DICE model when running the same scenario (see figure below).



CAPTION: Projected sea level rise resulting from the MESSAGE scenario produced by DICE (red) and MAGICC (blue).

The justification given for the high sea level rise projections in the DICE model (Nordhaus, 2010) is that they well-match the results of a "semi-empirical" methodology employed by Rahmstorf (2007) and Vermeer and Rahmstorf (2009).

However, subsequent science has proven the "semi-empirical" approach to projecting future sea level rise unreliable. For example, Gregory et al. (2012) examined the assumption used in the "semi-empirical" methods and found them to be unsubstantiated. Gregory et al (2012) specifically refer to the results of Rahmstorf (2007) and Vermeer and Rahmstorf (2009):

> The implication of our closure of the [global mean sea level rise, GMSLR] budget is that a relationship between global climate change and the rate of GMSLR is weak or absent in the past. The lack of a strong relationship is consistent with the evidence from the tide-gauge datasets, whose authors find acceleration of GMSLR during the 20th century to be either insignificant or small. It also calls into question the basis of the semi-empirical methods for projecting GMSLR, which depend on calibrating a relationship between global climate change or radiative forcing and the rate of GMSLR from observational data (Rahmstorf, 2007; Vermeer and Rahmstorf, 2009; Jevrejeva et al., 2010).

In light of these findings, the justification for the very high sea level rise projections (generally exceeding those of the IPCC AR5 and far greater than the IWG-accepted MAGICC results) produced by the DICE model is called into question and can no longer be substantiated.

Given the strong relationship between sea level rise and future damage built into the DICE model, there can be no doubt that the SCC estimates from the DICE model are higher than the best science would allow and consequently, should not be accepted by the OMB as a reliable estimate of the social cost of carbon.

We did not investigate the sea level rise projections from the FUND or the PAGE model, but suggest that such an analysis must be carried out prior to extending any confidence in the values of the SCC resulting from those models—confidence that we demonstrate cannot be assigned to the DICE SCC determinations.

High Social Cost of Carbon Estimates

A few papers have appeared in the recent scientific literature that have argued that the SCC should be considerably higher than that determined by the IWG. However, these papers suffer from serious flaws.

For example, Van den Bergh and Botzen (2014) purport to make a "conservative" estimate of the SCC that is nearly four times larger than the central estimate made by the IWG. This estimate suffers from the many of the issues described previously—a low discount rate, high climate sensitivity, and little to no positive benefits from agriculture. By including all sorts of imagined bad climate outcomes—with high monetary damages—and being largely dismissive of positive impacts, high SCC values are readily created by the authors.

Another recent analysis which arrived at an estimate of the social cost of carbon that was considerably higher than those made by the IWG was conducted by Moore and Diaz (2015). However, a careful examination shows that the assumptions made and methodologies employed therein produce a non-robust and ultimately unreliable result (McKitrick, 2015). Applying a better and more thorough methodology leads to results which are virtually opposite to those initially reported by Moore and Diaz (2015)—one in which the social cost of carbon is quite low and perhaps even positive.

According to McKitrick (2015), the major underlying flaw in the Moore and Diaz paper is the reliance on the results of Dell et al. (2012) in which a warming climate was linked to economic declines in both rich and poor countries. Using a more up-to-date dataset, McKitrick shows that the negative economic linkage to a warming climate is statistically insignificant and "not a robust basis for a policy assertion."

Furthermore, McKitrick (2015) shows that if a the more standard methodology is applied, where the temperature changes are areally-weighted rather than weighted by country-level population, the relationship between economic growth and temperature change reverses for rich countries and becomes statistically significant. According to McKitrick (2015), "each degree of warming significantly *increases* the annual income growth rate in rich countries by over 2 percentage points," while in poor countries, the relationship "is statistically insignificant."
In conclusion, McKitrick (2015) finds:

> The fact that the relevant poor-country coefficients are statistically insignificant implies they should not have been relied upon in Moore and Diaz (2015). And

> since the rich country coefficient corresponding to the [integrated assessment model] IAM structure is positive and significant, Moore and Diaz (2015) should actually have reported an acceleration of economic growth in rich countries associated with rising temperatures and a correspondingly reduced SCC. Also, since the rich countries begin with a larger GDP it is also likely that the overall global effect of warming on income growth would be positive, even applying the poor country coefficient. In any case the computations in Moore and Diaz (2015) are uninformative since they used coefficients from DJO based on an incomplete sample and a definition of temperature incompatible with their IAM.

Bottom line is that the Moore and Diaz (2015) high SCC estimates as well as the Dell et al. (2012) results upon which they were based, do not stand up under careful re-analysis. In fact, when assessed properly, they produce a low SCC estimate, in support of our overall analysis.

And finally, Havranek et al. (2015) reviewed the collective literature on the social cost of carbon estimates (809 estimates across 101 studies) and concluded that it suffers from selective reporting—with negative values (i.e., social benefits of carbon dioxide emissions) being largely downplayed or unreported. According to Havranek et al.:

> Our results are consistent with a situation when some authors of primary studies report preferentially estimates for which the 95% confidence interval excludes small values of the SCC, which creates an upward bias in the literature. In other words, we observe that small estimates of the SCC are associated with less uncertainty (expressed as the approximate standard error used to compute the lower bound of the confidence interval) than large estimates. The finding suggests that some small estimates with large uncertainty—that is, not ruling out negative values of the SCC—might be selectively omitted from the literature. Our results also indicate that selective reporting tends to be stronger in studies published in peer-reviewed journals than in unpublished manuscripts.

After applying a correction for the selective reporting, Havranek et al., conclude that the *upper* bound for the SCC from the collective literature is close to the *mean* value determined by the IWG—an indication that the IWG mean value is inflated:

> The result is USD 39 (= 134 · 1.07/3.67), which suggests that the upper boundary for mean estimates reported in the literature and corrected for selective reporting is remarkably close to the central estimate of 40 used by the US Government's Interagency Working Group on Social Cost of Carbon (IWGSCC, 2015).

Further, and rather importantly, Havranek et al., note that selective reporting likely plagues other aspects of the climate change literature, further leading to an inflated SCC value as produced by the IWG:

> Moreover, other studies suggest that some of the parameters used for the calibration of integrated assessment models, such as climate sensitivity or the elasticity of intertemporal substitution in consumption, are likely to be

> exaggerated themselves because of selective reporting, which might further contribute to the exaggeration of the SCC reported in individual studies—including the results of the Interagency Working Group.

Overall, these new papers provide additional evidence as to the non-robust nature of current SCC determinations.

Conclusion

The social cost of carbon as determined by the Interagency Working Group in their May 2013 Technical Support Document (updated in November 2013 and July 2015) and used by the DOE in its proposed Energy Conservation Standards for Manufactured Housing is unsupported by the robust scientific literature, and fraught with uncertainty and illogic that it is completely unsuitable and inappropriate for federal rulemaking. As such, use of the SCC in cost/benefit analyses in this proposed rulemaking should be suspended and not revisited until to above-mentioned weaknesses are fully rectified.

Given the uncertainties that are involved, the DOE should cease the use of the SCC in this and all regulatory cost/benefit analyses.

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