Expert Report

The Use of the Social Cost of Carbon in the Federal Proposal "Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks. [83 Fed. Reg. 42,986 (Aug. 24, 2018)]"

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Maximilian Auffhammer – Biographical Statement

I am the George Pardee Jr. Family Professor of International Sustainable Development at the University of California Berkeley, where I have been a professor in the Department of Agricultural & Resource Economics and the College of Letters and Sciences since 2003. I currently serve as the Associate Dean of Interdisciplinary Social Sciences in the College of Letters and Sciences, the Regional Associate Dean in Social Sciences, Arts and Humanities and the Undergraduate Division, as well as the Director of the Global Studies Graduate and Undergraduate Program. I am a research associate at the Energy Institute at Haas, a Fellow of the CESifo network and a research associate at the National Bureau of Economic Research as well as a Humboldt Fellow. I teach Ph.D. level econometrics, microeconomic theory to MBA students at the Haas School of Business and microeconomic theory, macroeconomic theory, economics of climate change and research methods to graduate and undergraduate students across the university.

My research areas include environmental and energy economics, climate economics, regulation, and forecasting. My geographic areas of expertise are the US with a focus on California, China, India and Europe. I have won many research awards, including grants from the National Science Foundation, the Environmental Protection Agency, and private foundations. I have conducted research on the economics of greenhouse gas (GHG) emissions, climate change impacts, energy consumption and production, and have analyzed the economic impacts of various regulatory programs carried out under the Clean Air Act.

I was appointed by the American Statistical Association to serve as a member of the Statistical Advisory Board to the Energy Information Administration in the Department of Energy. I chaired the advisory board for two years. I was also appointed to serve on a National Academies of Sciences Panel to assess the social cost of carbon (SCC). I served as a lead author on the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC). My research has won the Cozzarelli Prize for best paper in the prestigious Proceedings of the National Academies of Sciences. I have published extensively in the areas of environmental, energy and climate economics, and the economics of regulation. I advise governments on the design and evaluation of environmental and energy policies. For example, I advised the State of California in the renewal of its Carbon Market. I have advised the California Energy Commission, California Air Resources Board, US Environmental Protection Agency and the Central Intelligence Agency. I am a member of the American Economic Association and the Association of Environmental and Resource Economists. From September 2015 until August 2016 I served for the duration of the independent panel convened by the National Academies of Sciences titled "Assessing Approaches to Updating the Social Cost of Carbon". The National Academies of Sciences provide nonpartisan, objective guidance for decision makers on pressing issues. They bring together experts from across disciplines to look at the evidence. The study committees "survey the landscape of relevant research, hold public meetings to gather information, and deliberate to reach consensus, which results in a shared understanding of what the evidence reveals and the best path forward". The SCC panel issued an interim and final report recommending specific short term and long term updates to the Social Cost of Carbon (NAS, 2016).

The opinions and conclusions in this report are mine. I have attached a copy of my curriculum vitae as an appendix to this report.

Executive Summary

In my comments below I identify seven issues with the Social Cost of Carbon (SCC) used in the proposed rule titled "Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks. [83 Fed. Reg. 42,986 (Aug. 24, 2018)]".

First, the proposed rule employs a domestic social cost of carbon when the economically correct number is global, since the emissions of greenhouse gases and consequential impacts on the US and its citizens do not stop at the US border.

Second, the analysis is inconsistent with Circular A-4, which asks that impacts beyond the US borders should be reported separately. EPA (2018) provided the necessary values of the global Social Cost of Carbon, which enabled NHTSA to report the full damages of carbon emissions, but NHTSA failed to use these in its analysis and did not consider the global social cost of carbon. .

Third, the simplistic way in which the domestic social cost of carbon was calculated is a crude approximation and leaves out important spillover effects on the United States via capital owned by US firms abroad, national security implications and important effects on trade flows and global commodity markets.

Fourth, by using a domestic SCC, the analysis places zero weight on the welfare of the men and women serving in the US armed forces abroad as well as US citizens living abroad.

Fifth, the analysis places an extremely low weight on the well-being of future generations by using discount rates of 3% and 7%, which is not consistent with best available science suggesting a rate close to 2%.

Sixth, NHTSA did not implement any of the updates suggested by the National Academies of Sciences, even though many of the suggestions have already been implemented in the peer reviewed literature and are hence readily available. The most glaring omission is the lack of updates to the antiquated damage functions, which are mathematical functions translating changes in climate into economic damages, in the Integrated Assessments used to calculate the SCC.

Finally, recent peer reviewed science published in a top journal suggests a domestic social cost of carbon of $48, which is much higher than the $1-7 used in the current analysis.

I hence conclude that the SCC

a) does not represent best available science for multiple reasons
b) was modeled in a way that intentionally pushed the number toward zero at the expense of scientific integrity
c) is not consistent with circular A-4 by not evaluating the consequences of the proposed rule for US citizens living and serving abroad.

On August 24, 2018 the National Highway Safety Administration proposed a rule titled the "Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks. [83 Fed. Reg. 42,986 (Aug. 24, 2018)]". I have reviewed the proposed rule and the Preliminary Regulatory Impact Analysis (PRIA) as posted in the Federal Register. I have also reviewed the "12866 Review Materials for The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks NPRM; RIN 2060-AU09" as posted on regulatons.gov. The proposed rule makes sweeping changes to the required fuel efficiency of the model years 2021-2026. The proposed rule is argued to result in fewer miles driven (as less efficient vehicles have a higher cost per mile), increases in the emissions of greenhouse gases and local pollutants and significantly lower fatalities. While I take issue with large portions of the assumptions underlying the analysis to evaluate the proposed rule as well as the analysis itself, I will focus my comments on the evaluation of the damages from the emissions of greenhouse gases. My comments below are my own.

The Social Cost of Carbon – Summary

Carbon Dioxide is one long lived greenhouse gas emitted by natural and anthropogenic processes. Once emitted it affects the global climate over very long time periods (hundreds of years). The consequences of higher greenhouse gas emissions include changed temperature, precipitation and cloud patterns, sea level rise as well as the increased intensity and possibly frequency of extreme events. Further, higher greenhouse gas concentrations result in an increased probability of irreversible catastrophic events (IPCC, 2013). A changed climate affects both market and non-market sectors of the economy. On the market side it affects agricultural production (Schlenker and Roberts, 2009), energy demand (Auffhammer, Baylis and Hausman, 2017), productivity of labor (Graff-Zivin and Neidell, 2013), and the overall value of goods and services produced in economies across the world (Burke, Hsiang and Miguel, 2015) to name but a few. The National Climate Assessment provides a more comprehensive review of impacts for the United States (Melillo et al, 2014). On the non market side, a changed climate affects the distribution of species (Parmesan and Yohe, 2003), mortality (Deschenes and Greenstone, 2011), violent and non violent crime (Hsiang, Burke and Miguel, 2013), cognition (Graff-Zivin, Hsiang and Neidell, 2018), and the incidence and intensity of violent conflict worldwide (Hsiang, Burke and Miguel, 2013). There have been five large international efforts to synthesize the impacts globally (IPCC, 2015), as well as for the US (National Climate Assessment) and at the state level (California Climate Assessments).

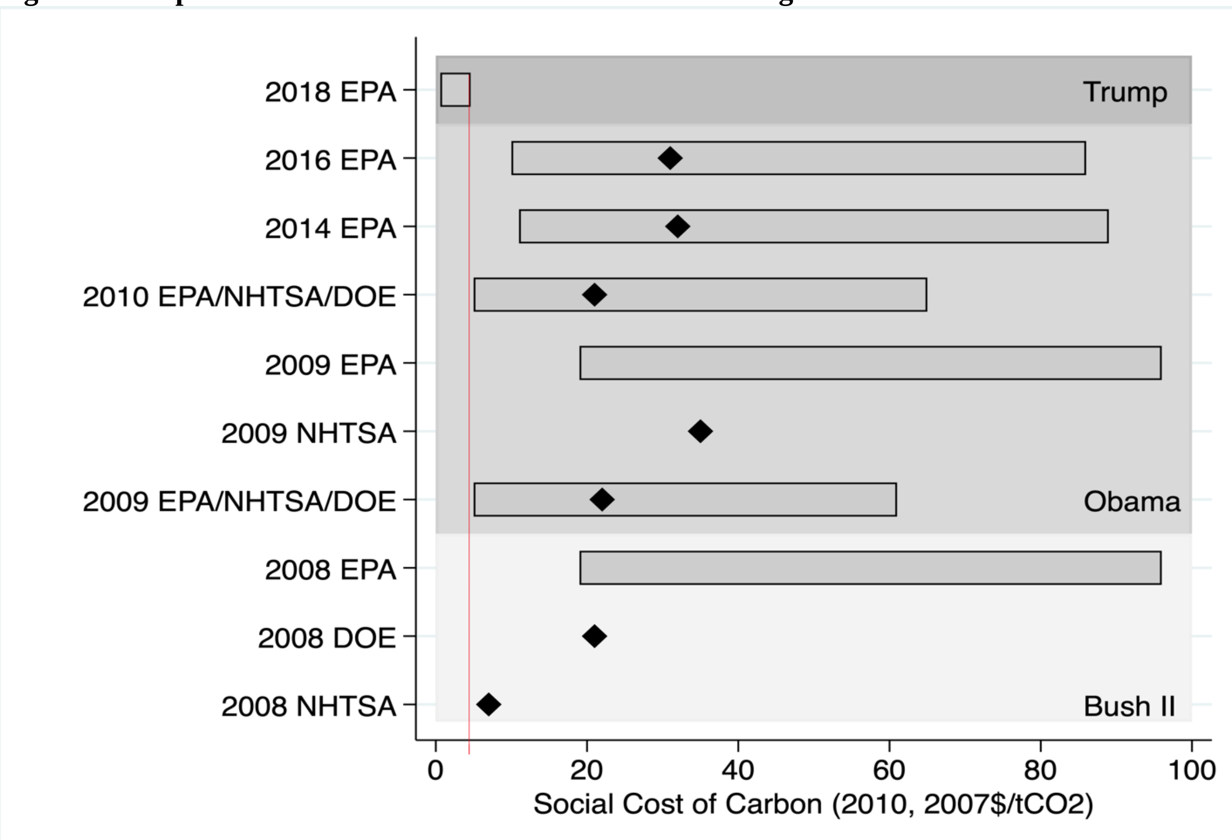
The Social Cost of Carbon is an estimate of the present value of the stream of global damages from one additional ton of CO_2 emitted at a point in time. In order to calculate this number the literature has employed so called Integrated Assessment Models (Greenstone et al. , 2013), which integrate simple models of the economic and climate system. These models start with assumptions about the evolution of global, and in some cases regional, income and population over the next 300 years. These are sometimes referred to as socioeconomic scenarios. The models then translate economic activity into emissions of greenhouse gases, most notably CO_2, but in some cases other GHG such as methane. These 300 year time paths of emissions are then fed into a model of the global climate system, which translates emissions into surface temperature, precipitation and sea level rise. These outputs are then fed to a set of so called damage functions, which map the emissions path into economic damages. For example, a hotter state of Georgia will likely use more electricity to cool the indoor environment due to climate change. This is considered an economic damage. In order to calculate the effect higher emissions have on outcomes of interest across many sectors of the economy, the Integrated Assessment Model is run with and without one additional ton of CO_2. The time path of the difference in damages relative to the baseline represents the damages from that one ton for each year over the next 300 years. The stream of damages is then discounted into a present value. This dollar amount is called the Social Cost of Carbon and is measured in US$.

Some Integrated Assessment Models have no spatial resolution and are global (e.g. DICE by 2018 Nobel Laureate William Nordhaus) and others break out the world into regions (e.g. PAGE by Chris Hope;

FUND by David Anthoff and Richard Tol). In the case of models with regional resolution, damages are aggregated across regions to calculate the *global* Social Cost of Carbon. This number represents the damages caused globally over time by one additional ton of CO_2 emissions. As US EPA (2016) shows, this cost is rising over time, as emissions later in time are generally understood to be more damaging due to the elevated stock of greenhouse gases in the atmosphere, and because GDP grows over time and some damage categories are modeled as proportional to GDP (US EPA, 2016).

The Federal Government has employed the Social Cost of Carbon in rulemakings since 2008. Figure 1 below, which is forthcoming in Auffhammer (2018), shows a set of values used by the three last administrations in federal rulemaking. For comparability, the graphic shows values for one ton of CO_2 emitted in the year 2010 valued in 2007 US$.

Figure 1: Sample of SCC estimates used in Federal Rulemakings For Three Administrations.



Note: Estimates for the SCC are for emissions of a ton of CO_2 in 2010 in 2007 dollars. NHTSA—National Highway and Traffic Safety Administration; IWG—Interagency Working Group; EPA—Environmental Protection Agency; DOE—Department of Energy. The black diamond indicates the "central estimate", if one was identified. The grey bars indicate selected upper and lower bounds used in regulatory analyses. The red line indicates the high scenario for the NHTSA SCC, which is lower than any of the other numbers used for central cases. Sources: Rose (2012); Rose et al. (2014); US EPA (2016); US EPA (2018).

In the early years of the Obama Administration, the Interagency working group comprised of members from the Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of the Interior, Department of Transportation, Department of the Treasury, Environmental Protection Agency, National Economic Council, Office of Management and Budget, and the Office of Science and Technology Policy embarked on an effort to calculate an official Social Cost of Carbon. The approach adopted, which is described in detail in Greenstone, Kopits and Wolverton (2013), was to feed three integrated assessment models with a set of harmonized assumptions regarding the evolution of the economy and population, account for parametric and scenario uncertainty and provide a distribution of the Social Cost of Carbon across models. The adopted discount rates were 2.5, 3 and 5%. The number, which has since been employed in the majority of economic studies on the external costs of climate change was $42 per ton emitted in 2020 as measured in 2007 dollars (note that the graph above shows the values for 2010 emissions – not 2020). This is the global number using a 3% discount rate. The officially published figures did not provide a domestic number. There were several updates to the social cost of carbon and the final available estimates prior to the National Academies of Sciences Report are given in the table below.

Table 1: Social Cost of Carbon Estimates by Interagency Working Group (US EPA, 2016).

	Discount Rate and Statistic			
Year	**5% Average**	**3% Average**	**2.5% Average**	**High Impact (95th pct at 3%)**
2015	$11	**$36**	$56	$105
2020	$12	**$42**	$62	$123
2025	$14	**$46**	$68	$138
2030	$16	**$50**	$73	$152
2035	$18	**$55**	$78	$168
2040	$21	**$60**	$84	$183
2045	$23	**$64**	$89	$197
2050	$26	**$69**	$95	$212

Source: US EPA (2016)

Table 1 displays the global SCC estimates using three different discount rates for emissions between 2015 out until the year 2050. Two things stand out from this table First, columns 2-4 display the average SCC across simulations using three different discount rates. A higher discount rate (5%) puts a lower value on future damages and hence results in a lower SCC. A lower discount rate places a relatively higher value on future damages and hence results in a higher SCC. For a ton emitted in 2050, the difference in the SCC using the 5% discount rate is less than one third of the value if one used the 3% discount rate. I discuss this further below.

Second, one notices that for any chosen discount rate, the SCC is higher the later emissions are made. For example, one ton of CO_2 emitted in 2020 using the 3% discount rate results in a $42 per ton SCC. A ton emitted in 2050, using the same discount rate, has an SCC of $69. This increase is due to two reasons. First, as time goes on the stock of CO_2 in the atmosphere is higher, as CO_2 accumulates over time. Hence, each additional ton emitted at a later point in time arrives in an atmosphere with a higher stock of CO_2 in it adding additional forcing into a "more stressed" system leading to higher damages. Second, for some of the IAMs used, damages are a function of income (e.g. GDP). As the world grows richer over time, later emissions arrive in a wealthier world resulting in higher damages. An easy way to think about this is, for example, higher incomes result in more valuable infrastructure, which may be negatively affected by changes in climate.

While the Interagency Working Group effort represented the first harmonized multi-model effort, the Obama White House asked the National Academies of Sciences to convene a panel of experts to evaluate the approach taken by the IWG and the panel issued a number of recommendations for short and long term improvements to the modelling. The NAS (2017) document states:

> "[...] the committee recommends near-term changes given the current state of the science. The recommended changes would be feasible to implement in the next 2-3 years and would improve the performance of each part of the analysis with respect to the primary criteria.
>
> • The socioeconomic module should use statistical methods and expert judgment for projecting distributions of economic activity, population growth, and emissions into the future.
>
> • The climate module should use a simple Earth system model that satisfies well-defined diagnostic tests to confirm that it properly captures the relationships between CO_2 emissions, atmospheric CO_2 concentrations, and global mean surface temperature change and sea level rise.
>
> • The damages module should improve and update existing formulations of climate change damages, make calibrations transparent, present disaggregated results, and address correlation between different formulations. This update should draw on recent scientific literature relating to both empirical estimation and process based modeling of damages.
>
> • The discounting module should incorporate the relationship between economic growth and discounting. The committee also recommends that the IWG provide guidance on how the SC-CO_2 estimates should be combined in regulatory impact analyses with other calculations.
>
> In addition, the committee details longer-term research that could improve each module and incorporate interactions within and feedbacks across modules. These advances will require significant investments in both economic and climate modeling research, particularly research related to the assessment of climate damages and to socioeconomic and emission projections."

Almost two years have passed since the issuing of these recommendations. During these two years the IWG has been disbanded by the Trump administration and no effort has been made by the federal government to address the recommendations. The capacity to incorporate the recommendation does still exist at the EPA and there is no good scientific reason not to proceed with updating the out of date science underlying current SCC estimates. In what follows, I provide a list of specific critiques of the modelling of the social cost of carbon as part of this proposed rule, which I conclude makes the analysis seriously flawed, biased and inconsistent with best available science. It further fails to place equal value on US citizens, which is inconsistent with Circular A-4 as I explain below.

Critique 1: The economically correct social cost of carbon is the global number, not a domestic number.

Going back to Harry Sidgwick (1838-1900) and Arthur Pigou (1877-1959), the concept of external costs has been central to the economic theory of the environment and was central to work underlying this year's Nobel Prize in Economic Sciences to Bill Nordhaus – the architect of the most influential Integrated Assessment Model, which was one of the three IAMs used by the Interagency Working Group to calculate the social cost of carbon.

If private agents (consumers, firms) do not pay for the full opportunity cost of their actions they will, when there are negative externalities, produce an inefficiently large amount of the externality (e.g. GHGs). This means that there is a difference between the cost of the activity to the agent (e.g. firm) and the whole of society due to the agent's activity.

If, as in the case of greenhouse gases, the costs to society are higher than those to the agent, the government needs to step in to fix the market failure and move society to the socially efficient output level. This is taught in all economics 101 classrooms across the globe. This does not mean that all emissions should be abated, but certainly some. Pigou, in one of the most important papers in all of economics, pointed out that one way to correct the inefficiency form the externality market failure is to charge consumers the marginal external cost of their activity in the form of a tax. This is the underlying motivation for a carbon tax.

If the regulator is more broadly engaged in the design of rules and regulations and comparing the benefits and costs of said regulation, (s)he needs to incorporate the external costs in the evaluation of policies. The Social Cost of Carbon is such an estimate. In the case of greenhouse gases, damages of a ton of CO_2 emitted in the United States occur domestically *and* abroad. Damages from emissions in India cause damages in the United States, China, the US and elsewhere. Greenhouse gases are a global pollutant and in order to obtain the economically efficient outcome globally, each country – including the United States – needs to use the global social cost of carbon in estimating the benefits and costs of regulation. If each country used its domestic Social Cost of Carbon in order to evaluate the optimal amount of abatement, the world would fall drastically short of the efficient level of abatement required to move global society to the optimal level of greenhouse gas emissions. This would be inefficient for the United States as other countries would produce inefficiently high emissions [Tease out that NHTSA would be first domino].

Further, the proposed rule *incorrectly* refers to an "international" cost of carbon. But global and international are two different things. International refers to a collection of at least two countries. Global refers to all countries. The "international" cost of carbon is not a recognized concept and I have never seen it mentioned in my 20+ years of working on climate change and the economics of climate change.

The issue as to whether the global or domestic SCC captures the correct damages was pointed out by EPA in previous rulemakings. One of the earliest technical policy documents on the subject acknowledges that writing US regulation based on a domestic social cost of carbon results in an inefficient outcome, resulting in inefficiently large damages imposed on all countries – including the United States. For example, the technical support document underlying the 2008 "Regulating Greenhouse gas emissions under the Clean Air Act" document, which was written during the Bush administration states that

> "because GHGs are a global pollutant, economists point out that, to achieve an efficient economic outcome (i.e., maximize global net benefits), countries would need to mitigate up to the point where their domestic marginal cost equals the global marginal benefit (Nordhaus, 2006). Net present value estimates of global marginal benefits internalize the global and intergenerational externalities of reducing a unit of emissions and can therefore help guide policies towards an efficient level of provision of the public good."

It goes on to say that

> "Individual countries may only consider the domestic marginal benefit of emissions reductions when making policy decisions. In this case, a country would aim to reduce its domestic GHG emissions up to the point where its domestic social benefit for the next increment of emissions reduction was equal to its domestic cost of that reduction. The mitigation undertaken would generate both domestic benefits and positive externalities for other countries. Thus, the emissions reductions associated with this domestic policy would be lower than if all the international externalities had been internalized. <u>This means there would continue to be a (global) market failure because the remaining domestic emissions are produced without accounting for their full cost to society</u>, i.e., the international (inter-temporal) externalities."

Hence which SCC a country uses has implications for which value other countries will use. This point is made in Kotchen (2016), who points out that "[…] all countries have a strategic SCC greater than their domestic SCC" suggesting that the relevant value of the SCC is higher than the domestic number.

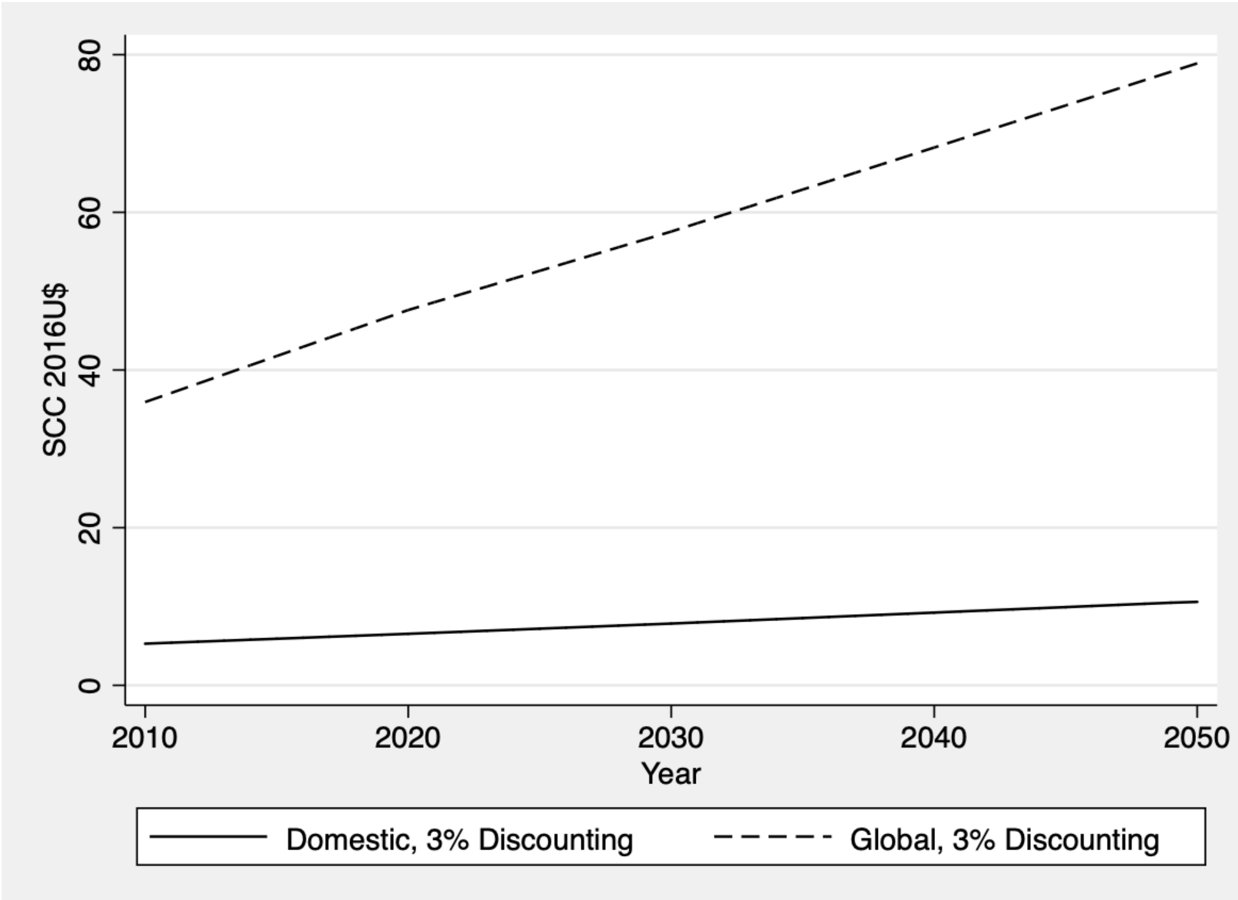
Using the domestic number is simply wrong from an economic perspective and does not represent best available science. In addition to the fact that this is not good economics, I argue below that one cannot credibly calculate this number with the current models.

Critique 2: The agencies did not conduct best available science by failing to provide a scenario using the global SCC, even though the necessary numbers were provided to them by EPA.

Analyses conducted under previous administrations, as indicated in figure 1, have used the global number for the SCC and in some cases provided estimates for a domestic SCC and calculated scenarios which included runs with a domestic SCC estimate. The current modelling abandoned the global cost of carbon in favor of a domestic social cost of carbon and failed to even conduct a sensitivity test or scenario, which includes the global number. This was not done because the information was not available to NHTSA. The docket of documents posted on regulations.gov includes an email between OMB and EPA relating to the inclusion of other greenhouse gases in the analysis (Social cost of carbon email exchange between EPA and OMB, July 16, 2018; Social cost of carbon spreadsheet provided by EPA to OMB, July, 16, 2018).

In that email EPA provided modelers with the Global and Domestic numbers, as indicated by documents and spreadsheets published on the dockets. There is hence no reason why this could not have been included as a scenario in the analysis. This is equivalent to adding one line of code to a computer program. Not including the global estimates as the central case, or even a robustness case is a violation of what is considered "best available science" and inconsistent with circular A-4, which states that "Your analysis should focus on benefits and costs that accrue to <u>citizens</u> and residents of the United States. Where you choose to evaluate a regulation that is likely to have effects beyond the borders of the United States, <u>these effects should be reported separately</u>." NHTSA failed to do this. Figure 2 below indicates the implications of this choice using the 3% discount rate and the actual data sent by EPA to OMB.

Figure 2: Domestic versus Global SCC (Email from EPA to OMB)



Source: US EPA (2018)

The graphic shows clearly that for any given year the global number is significantly larger than the domestic one – a roughly seven-fold difference. The domestic SCC for 2050 is $10.6, while for the global SCC using the same 3% discount rate us $78.90 in 2016 US$. This is likely to have major ramifications for the benefit cost analysis. NHTSA simply ignored the information it had and hence draws conclusions based on misleading and scientifically not defensible modelling choices. The cost of adding this analysis is essentially zero, since one literally has to change a small set of numbers in computer code they had to produce anyway, so there is really no reason why such analysis was not included.

Critique 3: The approach adopted to calculate a national number is at best an approximation and ignores important spillover effects.

As the National Academies of Sciences final report (NAS, 2016) indicates, the calculation of a domestic (or national social cost of carbon cannot be done credibly with the current models, as they ignore important spillover effects. While two of the models used in the analysis can produce estimates of local damages by simply spitting out numbers for the US region, this approach ignores a number of important spillover effects.

The first set of spillover effects stems from the fact that US companies own facilities all over the world. Negative impacts from climate change affecting production (e.g. conflict, productivity shocks, extreme events) will negatively affect US producer profits by affecting US production assets abroad. This could happen through assets directly owned by US corporations or assets owned by non-US entities that are critical to the supply chain of US owned corporations. By simply "chopping up" the map, these spillover effects are ignored.

Second, climate change will affect the global pattern of production and trade (Costinot, Donaldson and Smith, 2016). The domestic estimates of the Social Cost of Carbon ignore this restructuring of production and the US role in global economic activity. The effects of climate change on trade can be large. Again, "chopping up the map" assumes away the all important web holding the global economy together for the past and presumably next century and beyond.

The National Academies of Sciences report (2016) states that "There is an emerging literature that also incorporates interactions among regions and impacts […]. For example, given global markets, migration, and other factors, effects of a crop failure in India will also have impacts in other countries, and reductions in water availability in one region will have impacts across many regions and sectors. One set of interactions occurs through market mechanisms, such as trade. For example, the economic impacts of climate change on crop yield in one region will depend in part on the changes in crop yields in other regions. These interactions can be captured by multisectoral, multiregional economic computable general equilibrium (CGE) models. Models of global agriculture and forestry impacts have been developed over more than two decades […]. Impacts can also interact with each other, and with mitigation policy, through their effects on competition for resources, such as water and land." The current models do not capture any of these interactions in meaningful ways. To stress the point of how ad hoc the regional modeling was done, one need not look any further than how a domestic number was used for DICE. The agencies used the share of regional damages from another model by Bill Nordhaus (RICE) to estimate what share of damages are for the US region in *that other model* and using the percentage amount to "guesstimate" US damages in DICE. This is truly ad hoc and does not come close to representing best available science. In fact it is not even OK science. The simplistic and crude way the domestic SCC is calculated is at best an approximation not fit for rulemaking.

Critique 4: The domestic social cost of carbon places zero value on the welfare of our men and women in the armed forces serving abroad, now or in the future.

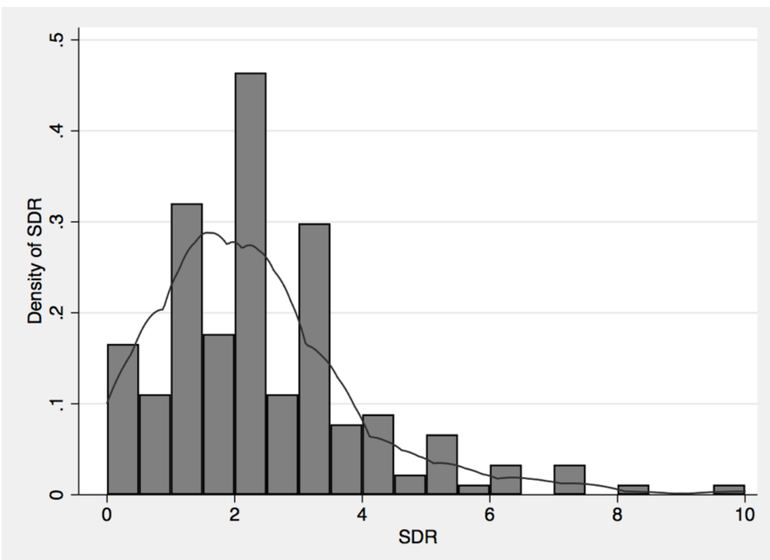
The US military has roughly 450,000 men and women stationed abroad (Brown and Gould, 2017). By their physical presence in other countries, they are exposed to changes in the environment directly. If climate change affects the environment where they are stationed, they will experience this changed climate first hand. If, as is the case, US emissions will cause this climate change abroad, there is a direct causal link between US emissions and the well being of US citizens abroad. Of course, this does not only hold for our men and women in uniform, but for any American citizen living or working abroad. The US department of state estimates that there are roughly 9 million US citizens living abroad. By using a domestic social cost of carbon in the way that the current rulemaking calculates it, the agencies are placing a value of $0 on the well being of men and women in uniform serving abroad and US citizens living abroad. This hence does not treat every US citizen equally, but puts a lower (zero) weight on anyone living abroad.

Further, climate change is projected to lead to an increase in the frequency of conflict domestically and globally, which will possibly result in the deployment of American Troops. This would have consequences in several dimensions. It would lead to more soldiers being deployed, whose welfare again according to the modeling is valued at zero. It would also lead to possible spillover effects from conflict, which are not captured in the current models. If increased conflict in a region disrupts supply chains by disruption of access to key resources like rare earths and scarce metals, climate change would cause damage abroad, which would translate into direct damages to stakeholders (e.g. corporations) in the United States, which is not captured in the current models.

Critique 5: The discount rates of 3% and 7% are not consistent with expert assessment of the discount rate.

The interagency work group used three discount rates: 2.5%, 3% and 5% and explicitly showed results for all three scenarios. The choice of discount rate is made by the modeler and there is a significant literature in environmental economics discussing approaches to discounting and the rate to be used. In order to arrive at what experts think the appropriate discount rate is, one conducts an expert elicitation. The most recent and comprehensive of these is forthcoming in a top economics journal (Drupp et al, forthcoming). In the paper they solicit expert responses as to what the discount rate should be and the results are not consistent with what has been done in the analysis underlying this rulemaking, which uses a 3% and 7% discount rate. The Drupp paper shows that the median discount rate is 2% and the mean discount rate is 2.27%. I have downloaded the data and confirmed these numbers. Figure 3 displays the distribution of the discount rate (referred to as the social discount rate) in this paper.

Figure 3: Social Discount Rates – Expert Elicitation (Drupp et al., forthcoming)



Source: Author Visualization of Drupp et al. (forthcoming)

An analysis of the data shows that less than 3% of the experts think that the preferred SDR is 7% or higher. Further 67% of experts stated that the number is lower than 3%. 62% of experts stated that the SDR is lower than 2.5%, which *is the lowest number considered by the sensitivity analysis in the current report*. What this means is that two third of experts in the field state that the discount rate applied in this proposed rulemaking is above what they believe to be scientifically preferred number.

The consequences of this choice are stark. If we compare the global SCC for 2020 in 2016 US$ discounted at 7% the number is $5.13. When discounted at the arguably still too high discount rate of 3%, the number becomes $47.60. At a 2.5% discount rate the global number is $71.22 (all estimates are taken from the posted spreadsheet by EPA (2018)). Hence, going from 7% to 2.5% represents a 13.9 fold increase in the SCC. And as argued above most experts in the most recent peer reviewed study believe that the 2.5% number is too high, which would make the social cost of carbon even higher. The same argument carries over to the domestic number. The domestic SCC for 2020 in 2016 US$ discounted at 7% the number is $0.98. When discounted at the arguably still too high discount rate of 3%, the number becomes $6.54. At a

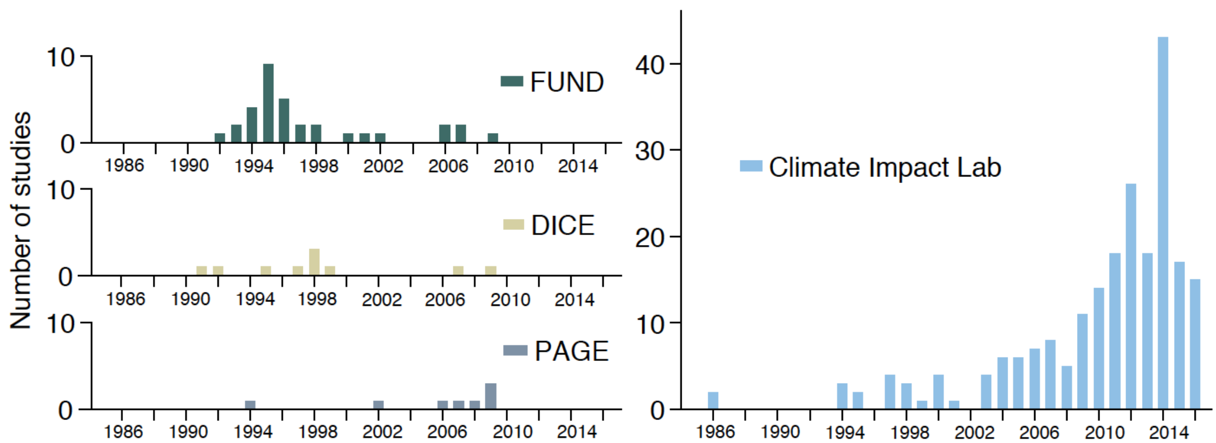
2.5% discount rate the domestic number is $9.47 (all estimates are taken from the posted spreadsheet by EPA).

Critique 6: The agencies did not use best available science by employing models relying on outdated representations of damage functions.

As the National Academies of Sciences Report (2016) points out, the current IAMs rely on severely outdated damage functions. In a presentation to the National Academies of Sciences, Professor Michael Greenstone (2016) of the University of Chicago showed a distribution of the publication dates of the studies underlying the damage components of the IAMs used in the calculation of the SCC used by the IWG and in this rulemaking. Not a single study published after 2010 is included. This means that the damage functions are almost a decade out of date. If one looks at the full distribution of the vintage of the included science, one can see that the majority of studies the SCC estimate for FUND is based on were published in the mid 1990s, which is 20 years ago. The distribution is similar for DICE and a bit more recent for PAGE.

The two questions one would want to answer then are, whether there is more recent science and whether this science has changed the damage functions. To answer the first question, one need only look at figure 4 below, where in the right panel it displays a review of the University of Chicago/Berkeley/Rutgers/Rhodium Climate Impact Lab, which shows an explosion of the literature since 2010. None of these papers are incorporated in the current SCC estimates. Hence, the SCC estimates do not reflect best available science by a decade.

Figure 4: Vintage of the literature used for the IWG IAMs (Greenstone, 2016)



Source: Greenstone (2016)

To answer the second question, one must recognize that the FUND model, for example, assumes that increases in temperature result in global increases in agricultural production. This damage function ignores a finding made in 2009 and which has been reconfirmed across crops and locations that extreme heat days are extremely damaging to crop yields. Scientific consensus at this point concludes that globally projected climate change will have negative impacts on yields (Chalinor et al, 2014). There are a number of sectors with similar findings, which have not been incorporated into the models.

The fact that *none* of these papers were incorporated in the modelling underlying this current rule is unacceptable and represents outdated and a state "far from best available science". The EPA has the skill and resources to do so, but was never instructed to update the science.

While I acknowledge that updating damage functions in IAMs is not a straightforward undertaking, several readily available projects were simply ignored. A recent paper by Moore, Hertel, Baldos and Diaz (2017) provide a readily available improved damage function for the agricultural sector for FUND for example. De Cian et al. (in press) provide estimates one could use for a damage function for the energy sector, which is the biggest source of damages in FUND. The Climate Impact Lab at the University of Chicago and Berkeley as well as Resources for the Future have made great progress in implementing the changes recommended by the National Academies of Sciences without readily a priori available modelling resources. The fact that none of the changes suggested by the independent National Academies of Sciences Panel were implemented by the agencies represents an intentional disregard for what is best available science. Failing to incorporate these recent scientific findings, is a disregard for science. And the consequences are grave. As Moore, Hertel, Baldos and Diaz (2017) conclude, "These new damage functions reveal far more adverse agricultural impacts than currently represented in IAMs. Impacts in the agriculture increase from net benefits of \$2.7/ton CO_2 to net costs of \$8.5/ton, leading the total SCC to more than double." To put this in plain language. Simply updating the damage function for one sector using peer reviewed damage functions from the IPCC, leads to triple the size of effects – in the opposite direction and a doubling of the SCC.

Critique 7: Current peer reviewed science in a top journal suggests a domestic SCC of \$48/ton of CO_2 for the US

A new paper by Ricke, Drouet, Caldeira and Tavoni (2018) released in the most recent issue of the top journal Nature Climate Change uses a more recent approach to quantify the market damages of climate change at the country level using the model by Burke, Hsiang and Miguel (2015) in the journal Nature. They use a statistical relationship to estimate the relationship between growth rates in per capita GDP across countries and temperature to calculate the impacts of climate change on GDP at the country level. This paper relies on the most extensive dataset of the measured value of goods and services and temperature at the country level over the recent historical record. It employs cutting edge statistical methods to quantify the impact of temperature shocks on economic output at the country level. It combines these statistical estimates with cutting edge climate science to estimate the SCC at the country level. Its shortcoming is that it ignores non-market impacts and spillover effects, which means a significant number of impact categories are left out of the analysis, which would push the SCC even higher.

This most recent modelling effort arrives at a US domestic SCC of \$48 per ton, which is of course much larger than the \$1-\$7 range NHTSA used. While this paper was not released at the time of the proposed rulemaking, it is now and the analysis should be redone using this most recent, actually peer reviewed, estimate of the domestic social cost carbon, if agencies incorrectly insist on using the domestic instead of the global number. Not doing so would again ignore the most recent peer reviewed record on the subject, as the analysis underlying this rule has consistently done.

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