A Guide to Updating the US Government's Social Cost of Carbon

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Introduction

Across the world, climate policies have the potential to provide large benefits by reducing the harms caused by carbon dioxide (CO_2) emissions. However, these policies can be costly, with some being more expensive than others. Moreover, the value of reducing emissions is not $0, nor is it infinite. Some policy options would impose stringent restrictions on emissions, while others would be more lenient. What level of stringency is optimal if a policy aims to reduce CO_2 emissions?

A key tool in identifying such policies is the social cost of carbon (SCC),[1] which measures the monetized value of all future net damages associated with a 1 metric ton increase in CO_2 emissions.[2] Thus, the SCC provides a measure of how much society should be willing to pay for a 1-ton reduction in CO_2 emissions and allows policy makers to compare a policy's benefits and costs, both measured in dollars. From the standpoint of law and practice, this conversion of CO_2 emissions into dollars is extraordinarily helpful. Indeed, in the United States, there is legislation requiring agencies to conduct benefit–cost analysis, and existing executive orders supported by both Republican and Democratic presidents require such an analysis for all major regulations, including those designed to reduce carbon emissions. In contrast, other proposed approaches for evaluating climate policy, such as defining a temperature target and identifying cost-minimizing policies to achieve it, do not have a strong legal basis (Sunstein 2022) and replace scientific assessment of costs and benefits with politically based rules (Aldy et al. 2021).

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We thank Jared Stolove for exceptional research assistance and Trevor Houser, Amir Jina, Robert Kopp, Ishan Nath, and Cass Sunstein for valuable critiques and suggestions.

[1]Throughout this article, the SCC refers to the social cost of carbon, as well as the social costs of methane and nitrous oxides, which are calculated using the same approach.

[2]The SCC theoretically captures all future net damages associated with a marginal increase in CO_2 emissions. However, as we will discuss, measuring all damages is challenging in practice.

Online enhancements: appendix, supplemental figures.

Electronically published July 19, 2022

Review of Environmental Economics and Policy, volume 16, number 2, summer 2022.

Published by The University of Chicago Press for AERE. https://doi.org/10.1086/720988

Ever since the US Supreme Court's decision in *US Environmental Protection Agency v. Massachusetts* (2007), the US government has been required to issue at least some regulations to reduce greenhouse gas emissions. However, in 2007, the government lacked a consistent SCC on which to base its judgments. In 2009, the Obama administration issued a temporary SCC (US EPA and NHTSA 2009) and formed an Interagency Working Group (IWG) tasked with developing a robust SCC based on the best available science and economics. This work was completed in 2010 (IWG on Social Cost of Carbon 2010) and later updated, ultimately resulting in an SCC value for 2020 of \$51 per ton of CO_2 (IWG on Social Cost of Carbon 2013). Using the same methods, social costs of methane and nitrous oxides (other potent greenhouse gases) were developed in 2016 (IWG on Social Cost of Carbon 2016).

Since its release in 2010, the SCC has played a central role in climate policy both domestically and internationally. Indeed, as of 2017, the US federal government had used the SCC to assess the value of more than 80 regulations, with estimated gross benefits of \$1 trillion (Nordhaus 2017). At least 11 state governments use an SCC to guide policy, most notably Illinois and New York, where the SCC is used to value "zero-emissions credits" paid to clean energy producers. Meanwhile, several other countries, including Canada, France, Germany, Mexico, Norway, and the United Kingdom, have developed their own SCC estimates, with some directly adopting the IWG estimates. The US SCC can also influence international climate negotiations since meaningful US climate action can leverage reductions in emissions from other countries (Houser and Larsen 2021).

The original IWG called for updating the SCC regularly to reflect advances in science and economics (IWG on Social Cost of Carbon 2010). Seven years later, a committee at the US National Academies of Sciences, Engineering, and Medicine (NASEM) was tasked with examining the SCC and confirmed the need for regular SCC updates (NASEM 2017). However, no substantial updates have been made since the 2010 IWG.

Several events and trends underscore the critical importance of updating the SCC. First, research over the past dozen years has relied on large-scale data sets to dramatically alter our understanding of the magnitudes of the projected physical and economic impacts of climate change (see figure 1). Second, this new empirically grounded research finds that climate change impacts are much more heterogeneous than previously assumed. For example, Hsiang et al. (2017) show that economic climate change damages in 2100 are projected to be approximately nine times larger in the poorest 5 percent of US counties than in the richest 5 percent. Finally, the legal durability of the SCC requires that it be based on frontier science and economics. This was highlighted in 2020 when a federal district judge struck down a Trump administration rollback of methane emissions standards that was based on a \$1–\$8 SCC, emphasizing that its calculation was "riddled with flaws" and characterizing the rollback as "arbitrary" and "capricious" (*California v. Bernhardt*).[3]

This article, which was written before and during the Biden administration's comprehensive update of the SCC,[4] makes recommendations for how the SCC could be revised to ensure

[3] These calculations provided the basis for weakening many environmental regulations (see figure S1; figures S1–S3 are available online).

[4] The update has been conducted over the course of 2021 and 2022 and is expected to be released in 2022 (IWG on Social Cost of Greenhouse Gases 2021).

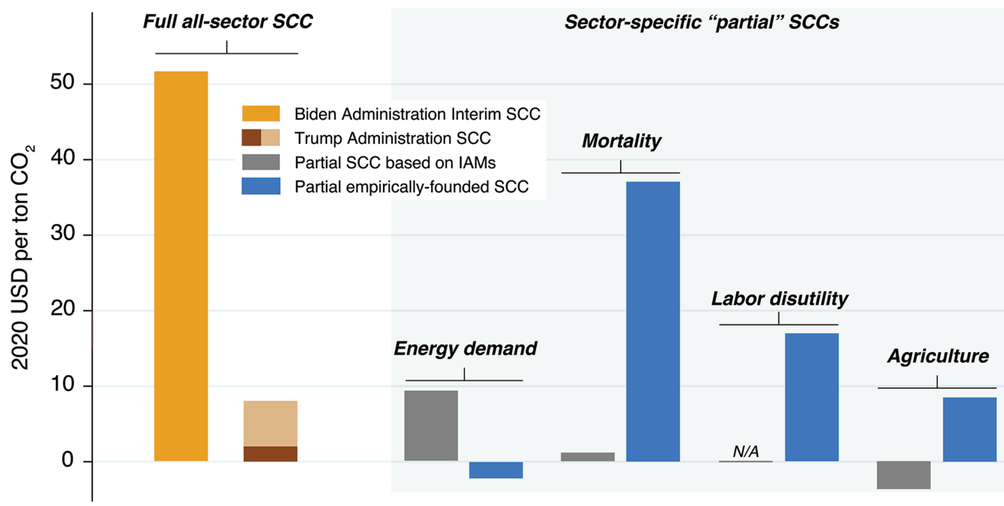

Figure 1 US SCC does not reflect the frontiers of science. Current and past US federal SCCs are compared with those produced by recent research. The all-sector SCCs shown on the left include values used by the Trump administration (brown) and the interim estimate under the Biden administration (gold), which relies on the same science and economics as the original 2010 SCC. Sector-specific "partial" SCCs on the right come from the IWG on Social Cost of Carbon (2013) implementation of the FUND model (one of the three models used to derive the US federal all-sector SCC; gray) and recent scientific literature (blue). Estimates represent the 2020 SCC under "business as usual" emissions (FUND partial SCCs and agriculture partial SCC), a set of emissions scenarios with a four-fifths weight placed on business as usual scenarios (all-sector SCCs), or a high-emissions scenario (RCP 8.5; energy, mortality, labor, and agriculture partial SCCs). Socioeconomic scenarios vary and reflect each author's central estimate. Discount rates differ across authors and administrations; the Trump administration's 3 percent (light brown) to 7 percent (dark brown) range is shown. Estimates are converted to 2020 US dollars using the annual GDP implicit price deflator in BEA (2021). Sources: Anthoff and Tol (2014); decomposed by Diaz (2014); Moore et al. (2017); Rode et al. (2021, 2022); Carleton et al. (forthcoming).

that it once again reflects the frontier of knowledge. We describe seven key "ingredients" that should go into such an update; thus, the article can be viewed as a "recipe" for revising the US government's SCC that is based on the best available science and economics of climate change.

The article is organized as follows. The next section describes each of the key ingredients, discusses how they have been approached in the past and the advances that have occurred since 2009–2010, and makes specific recommendations for revising them. The final section presents an implementation pathway for combining these ingredients into an updated SCC.

The Seven Key Ingredients for a Revised SCC

Calculating the SCC requires a model that accounts for future economic growth, the relationship between emissions and climate change, the effect of climate change on the economy, and multiple other factors. Such models are known as integrated assessment models (IAMs) because they combine scientific and economic models to evaluate the impacts of carbon emissions. The Obama-era IWG estimated the SCC using three IAMs: the dynamic integrated model of climate and the economy (DICE; Nordhaus 2010), the climate framework for uncertainty, negotiation, and distribution (FUND; Anthoff and Tol 2014), and the policy analysis of the greenhouse effect (PAGE) model (Hope 2011). These models were originally developed in the 1990s and have been widely used in the economic and scientific literature.

Seven ingredients are necessary to construct the SCC (figure 2). The first four ingredients, which are sometimes called "modules," are:

1. Socioeconomic and emissions trajectories that predict how the global economy and CO_2 emissions will grow in the future.
2. A climate module that measures the effect of emissions on the climate.
3. A damages module that translates climate changes into economic damages.
4. A discounting module that calculates the present value of future damages.

The last three ingredients are crosscutting modeling decisions that affect the entire SCC calculation process:

5. Whether to include global or only domestic climate damages.
6. How to value uncertainty.
7. How to treat equity.

Updating the SCC so that it is based on the best available science and economics requires that a new IWG make decisions regarding each of these seven ingredients. However, some of the updates that will be required are already clear. First, significant advances in climate modeling and climate impact analysis, as well as profound changes in global capital markets, mean that it is essential to update the climate and damage modules and to change the discount rate. Second, there is a very strong scientific, legal, and economic case for including global (rather than only domestic) damages (NASEM 2017; Sunstein 2022). Failing to make these updates would leave any new SCC vulnerable to both scientific criticism and legal invalidation. There are also opportunities to update the other three ingredients; however, the scientific and/or policy case for doing so is not as clear-cut.

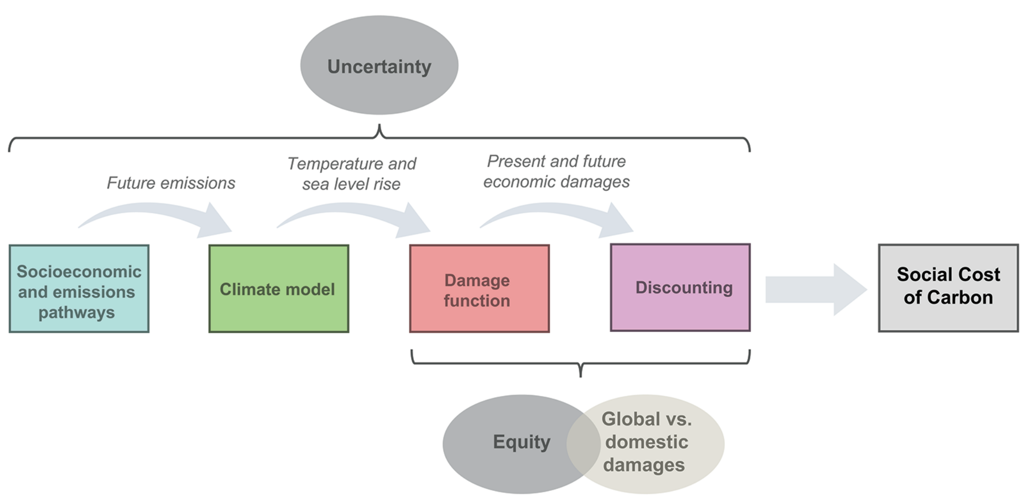

Figure 2 Seven key ingredients for calculating the SCC. The four "modules" (colored boxes) that compose the SCC and the three key modeling decisions (gray ovals), which together form the seven ingredients necessary to compute an SCC, are presented.

In the remainder of this section, we briefly describe each of the seven ingredients, outline the 2010 IWG approach to handling them, detail progress since then, and make recommendations for updating each of them.

Ingredient One: Climate Module

Any SCC calculation requires a climate model that converts carbon emissions into changes to the global climate. Specifically, these models characterize the relationship between emissions, atmospheric CO_2 concentrations, and changes in the climate, including warming and sea level rise. All three of the IAMs used by the IWG included highly simplified climate models. A core input into each model was equilibrium climate sensitivity (ECS), which determines the total global warming that results from a doubling of atmospheric carbon concentrations. Although ECS has a substantial impact on the SCC, its true value is not known with scientific certainty.

2010 IWG approach

The IWG relied on the climate models within each IAM. To ensure that the ECS values used reflected the best available science, the IWG used an ECS probability distribution that reflected the likelihood of different possible climate outcomes at the end of the century, as reported in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC; Solomon et al. 2007). The same distribution was used for all three models, and this was the only component of each IAM's climate model that the IWG adjusted to match scientific evidence.

Progress

Recent evidence makes clear that even when using the same ECS distribution, these IAMs are outdated because they do not accurately quantify the temperature response to changes in emissions (Hänsel et al. 2020; Montamat and Stock 2020; Dietz et al. 2021). In particular, DICE, FUND, and PAGE substantially underestimate the speed of warming relative to climate models that satisfy the scientific standards outlined by the NASEM (2017) report on the SCC. For example, higher atmospheric CO_2 concentrations cause the oceans to warm and acidify, which makes them less effective at removing CO_2 from the atmosphere. This leads to a positive feedback loop that accelerates warming (Dietz et al. 2021), but it is missing from both DICE and PAGE.[5]

The fact that existing IAMs do not reflect the current climate science literature has a significant effect on the SCC (Dietz et al. 2021). In particular, the delay in warming that occurs in the IAMs results in SCCs that are likely too low because it pushes warming further into the future, which is discounted more heavily.[6]

Recommendations

It is essential that an updated SCC rely on an accurate characterization of the climate system. However, because any SCC calculation requires fully capturing climatological uncertainty, it would be computationally infeasible to replace IAM climate models with state-of-the-art Earth system models that capture the physics, chemistry, and biology of the atmosphere,

[5]See figure S2.
[6]See the bottom panel of figure S2.

oceans, and land at high spatial resolution. Thus, we recommend relying on a simple Earth system model that can conduct uncertainty analysis while also matching the predictions about global mean surface temperature from full-complexity Earth system models. More specifically, we recommend that the finite amplitude impulse response (FAIR) model (Millar et al. 2017) be used to project changes in temperature.[7] The FAIR model satisfies all of the criteria set by the NASEM (2017) for use in an SCC, it generates warming projections that are consistent with full-complexity models (such as those composing the Climate Model Intercomparison Project Phase 6 ensemble; Eyring et al. 2016), and it can be used to characterize the uncertainty regarding the impact of an additional ton of CO_2 on global mean surface temperature. The FAIR model is easy to implement, is transparently documented,[8] and is already being used in some SCC updates (Hänsel et al. 2020; Dietz et al. 2021; Rode et al. 2021, 2022; Carleton et al., forthcoming).

A key limitation of simple climate models like FAIR is that they do not represent changes in global mean sea level rise. However, Kopp et al. (2016) and others have developed semiempirical models that enable the inclusion of damages due to both warming and projected sea level changes. Although semiempirical models have some limitations,[9] we recommend that they be used to project changes in sea level based on the changes in global mean surface temperature from FAIR.

Ingredient Two: Damages Module

A "damage function" translates physical climate changes such as temperature and sea level rise into monetized economic impacts or damages. Some IAMs use a single damage function to represent all categories of impact (e.g., PAGE), while others rely on separate damage functions for individual impact categories (e.g., FUND). Although DICE uses a single damage function, it is based on sector-specific damage estimates (Nordhaus 1992).

2010 IWG approach

In 2010, IAM damage functions were the only feasible option, and thus the IWG relied on the damage functions originally developed in DICE, FUND, and PAGE. These damage functions have at least two key drawbacks. First, they rely primarily on ad hoc assumptions and simplified relationships that were necessary to use when computing power and data access were more limited than they are today. Second, IAM damage functions treat the world as nearly homogeneous, dividing it into at most 16 regions. Such aggregation obscures nonlinearities in the relationship between temperature and human well-being. For example, a given increase in temperature will have very different impacts in Arizona than in Minnesota. However, these differences are missed when the United States is a single unit of observation. Because of these problems, these damage functions have been heavily criticized in recent years (Pindyck 2013).

[7] See the appendix (available online) for a discussion of how to combine climate projections from FAIR with high spatial resolution damage estimates.
[8] FAIR's source code can be accessed at https://github.com/OMS-NetZero/FAIR/.
[9] These models may underestimate sea level rise because of their inability to capture plausible future dynamics (e.g., ice cliff collapse) that are not observed in the historical record.

Progress

Over the past dozen years, advances in computing power, global data access, and econometric methods have led to an explosion of empirical research that has greatly deepened our understanding of the economic impacts of climate change (Carleton and Hsiang 2016). For example, in a review of the literature for this article, we identified 433 empirical studies on the economic impacts of climate change that were published between 2010 and 2021 alone.

Recommendations

To make full use of recent scientific advances in the climate impacts literature, we recommend that all existing IAM damage functions be replaced with damage functions that meet the following three criteria:

1. *Damage functions should be empirically derived and plausibly causal.* That is, damage functions should be derived from empirical estimates that reflect plausibly causal impacts of weather events on socioeconomic outcomes. Because the climate has remained stable throughout modern human history, plausibly random variation in the long-run climate is unavailable. However, a large and growing empirical literature uses modern econometric methods to identify causal impacts of short-run weather events on many socioeconomic outcomes, ranging from agricultural output to mortality rates (Dell, Jones, and Olken 2014; Carleton and Hsiang 2016). When combined with empirical estimates of differences in populations' responses to weather events (discussed below), this literature provides a strong foundation for understanding the socioeconomic effects of climate change (Hsiang 2016).

The IAM damage functions used by the IWG do not meet this criterion. They are only loosely calibrated to empirical evidence and/or rely on outdated estimates that fail to isolate the impact of climate from correlated variables, such as income and institutions. For example, FUND's damage functions rely on associational (i.e., not causal) studies published prior to 2000. Similarly, early versions of the DICE damage function were only weakly tied to data (Nordhaus 2010; Diaz and Moore 2017), while the recent DICE update relies on associational evidence (Nordhaus and Moffat 2017).

2. *Damage functions should capture local-level nonlinearities for the entire global population.* Damage functions should be estimated with data representing the entire global population and should account for nonlinear effects of climate variables at a local level. Recent empirical studies estimate climate change's impacts on social and economic conditions at the local level across the globe. This research has identified highly nonlinear relationships between socioeconomic variables and climate variables, indicating that the effects of climate change are not identical everywhere. For example, extreme cold and extreme heat increase mortality rates, while moderate temperatures have little impact (Deschênes and Greenstone 2011). This research has also found large differences in climate impacts between rich and poor (Davis and Gertler 2015), hot and cold (Heutel, Miller, and Molitor 2017), and agricultural and nonagricultural (Cai et al. 2016) regions. These differences across locations imply that the additional damage caused by an increment of warming will depend on specific characteristics of the local economy, demographics, and region.

Existing IAM damage functions do not adequately characterize nonlinearities, disaggregate impacts locally, or include information from lower-income, hotter regions. For example, the PAGE damage function is calibrated using data only from the United States (Cline 1992). Similarly, although the FUND mortality-specific damage function draws on multiple studies, only Martens (1998) leverages mortality data, and the data are only from Los Angeles, New York, Tokyo, Israel, the Netherlands, Taiwan, and the United Kingdom. None of these locations reflect the hot climate and low incomes that characterize the regions where several billion people currently live.

Figure 3 illustrates that a failure to capture globally representative, locally varying, nonlinear relationships threatens the validity of damage functions. More specifically, it shows that in Oslo, Norway, climate change is likely to save lives because the mortality rate is highly sensitive to cold, while low incomes in Accra, Ghana, lead to extremely high mortality sensitivity to heat and large increases in mortality under climate change. Figure 3 also shows that the global average mortality-temperature response function is a poor representation of the impact of climate change in both Oslo and Accra and that ignoring such heterogeneity would substantially misrepresent climate change impacts.

3. *Damage functions should include adaptation.* Damage functions should reflect the fact that people, firms, and governments will make costly defensive investments to protect against climate-related risks. More specifically, damage functions should include empirically based estimates of both the benefits and costs of future adaptive investments. However, the damage functions within DICE, FUND, and PAGE include very different assumptions about such compensatory investments and their costs, the majority of which are empirically unfounded (Diaz and Moore 2017).

Although earlier empirical studies excluded adaptation benefits (e.g., Deschênes and Greenstone 2007), an emerging literature is developing damage estimates that account for these benefits by quantifying how populations' responses to weather events vary with their average climate (e.g., Deryugina and Hsiang 2017; Heutel, Miller, and Molitor 2017; Auffhammer 2022). Because these compensatory investments are not free, updated damage functions should also account for adaptation costs. Some progress has been made to infer these costs from available data (Carleton et al., forthcoming), but further research is needed in this area.

Figure 1 shows that damage functions that meet the three criteria above lead to sector-specific climate damages that are substantially different from those in existing IAMs. For example, Carleton et al. (forthcoming) estimated a mortality-only SCC that is more than 10 times larger than the mortality SCC estimated with FUND. The Carleton et al. estimate of the loss from higher mortality rates in 2100 accounts for 49–135 percent of the estimated total damages across all sectors in the three IAMs. Moore et al. (2017), who derived an agricultural damage function that meets some (but not all) of the criteria above, found a substantial, positive, agriculture-only SCC, while FUND's agricultural SCC is negative.

It is important to note that meeting these three criteria will not always increase estimated damages. For example, Rode et al. (2021) estimated an energy-only SCC of −$2.[10] In contrast, the FUND model's energy-only SCC is $8 and accounts for 90 percent of the total SCC across all sectors (Diaz 2014).

[10]This finding was attributable to savings from reductions in heating and differences in the responsiveness of electricity demand to high temperatures in high- vs. low-income regions of the world.

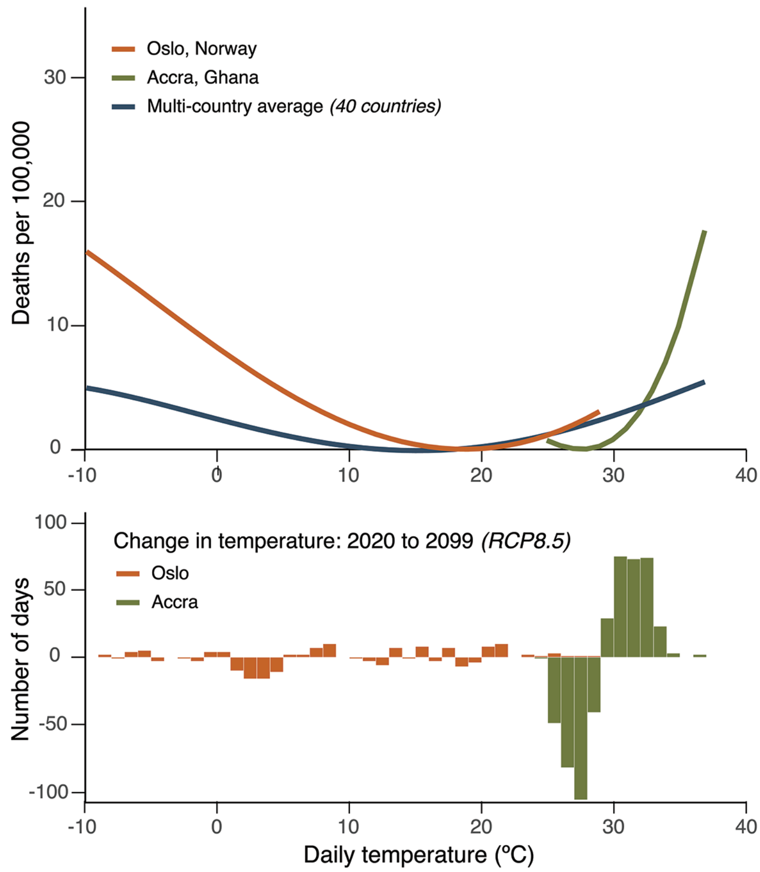

Figure 3 Climate change will have different impacts on different geographic regions. The estimated mortality-temperature relationships for ages >65 years (top panel), along with anticipated changes in the temperature distribution from climate change (bottom panel), are presented for Oslo, Norway (orange), and Accra, Ghana (green). The top panel includes an average mortality-temperature relationship (blue), estimated using subnational data from 40 countries. In the bottom panel, the difference between the 2099 and 2020 temperature distributions is shown using a high-emissions scenario (RCP 8.5) from a single climate model called Community Climate System Model, version 4. Top panel relationships are shown only for the range of temperatures projected to be experienced in each location between 2020 and 2099. Source: Carleton et al. (forthcoming).

Although these examples demonstrate that damage functions that meet the three criteria above will lead to very different estimates of the economic impacts of climate change,[11] such damage estimates are not currently available for all sectors affected by climate change.[12] However, this challenge cannot be addressed by existing IAMs: many difficult-to-quantify sectors, such as ecosystem services and human migration, are not included in the IAMs or are treated in an overly simplistic manner (Kopp and Mignone 2012).

[11]Another option for updating damage functions that is also guided by the three criteria above is a "top-down" approach that relies on statistical relationships between GDP and climate variables (generally temperature) to quantify the impacts of climate change on aggregate growth in (or levels of) income (e.g., Dell, Jones, and Olken 2012; Burke, Hsiang, and Miguel 2015). We discuss the merits and challenges of using such a top-down approach in the appendix.

[12]We discuss this challenge in detail in the next section and in the appendix.

Ingredient Three: Discount Module

A single additional ton of CO_2 emissions causes a trajectory of additional warming and a corresponding stream of future benefits and damages. The final step in calculating the SCC is to express the stream of net damages as a single present value so that the present value of all costs and benefits can be calculated and compared. The discount rate is the interest rate used to convert future impacts into present-day dollars. Because CO_2 emissions lead to climatological shifts that last multiple centuries, small differences in the choice of discount rate compound over time, which can lead to significantly different values for the SCC.

There are two reasons why it is important to discount future monetary amounts. First, an additional dollar is worth more to a poor person than a wealthy one; this is known as the declining marginal value of consumption. This concept is relevant for the SCC because climate change damages that occur in the future will matter less to society than those that occur today if future societies will be wealthier. The second reason to discount future monetary amounts, which is debated more vigorously, is the pure rate of time preference; this is the concept that people value the future less than the present, regardless of their income. Although some argue that the future and the present should be valued equally, conditional on income (e.g., Arrow et al. 1996), one rationale for a nonzero pure rate of time preference is the possibility that a disaster (e.g., asteroids or nuclear war) could wipe out the population at some future date, removing the value of any events that happen afterward and thus justifying a lower valuation of the future.

Given the clear economic case for discounting, US government agencies apply discount rates in benefit–cost analysis of all regulations, not just environmental policies. In general, agencies have followed the recommendations of the Office of Management and Budget (OMB) set forth in Circular A-4 and used 3 and 7 percent discount rates (OMB 2003).[13] These two values are based on observed market rates of return, with the 3 percent discount rate being a proxy for the real after-tax riskless interest rate associated with US government bonds and the 7 percent rate intended to reflect real equity returns, such as those in the stock market.[14] Asset pricing theory guides the decision concerning which of these two rates to use in any benefit–cost analysis on the basis of the payoff structure of the policy in question (Greenstone, Kopits, and Wolverton 2013). However, because climate change involves intergenerational trade-offs, it raises difficult economic, scientific, philosophical, and legal questions regarding equity across long periods of time. Thus, there is no scientific consensus about the correct approach to discounting for the SCC (Gollier and Hammitt 2014).

2010 IWG approach

The IWG faced a choice between two possible approaches to discounting in SCC calculations. First, a "descriptive" (and generally constant) discount rate that is derived from observed interest rates can be used. As discussed above, this is the approach recommended by the OMB for all government agencies. Second, a "prescriptive" discount rate can be derived based on the

[13]Circular A-4 (OMB 2003) guides the use of benefit–cost analysis across the US government.
[14]The riskless interest rate is the rate of interest on an investment with zero risk.

so-called Ramsey equation (Ramsey 1928).[15] Rather than relying on observed interest rates, this method derives a discount rate from assumptions about three parameters: the pure rate of time preference, the growth rate of consumption, and a parameter that captures the decreasing marginal utility of consumption.[16] There are large literatures that estimate values for the first and third parameters (Gollier and Hammitt 2014); the consumption growth rate will depend on the scenarios in the socioeconomic and emissions module described below.

The 2010 IWG used the descriptive approach with a fixed discount rate of 3 percent as the central case, consistent with OMB guidance.[17] The selection of 3 percent was motivated by a 2003 calculation of the real interest rate on US government 10-year bonds that approximates the riskless interest rate. The choice of the riskless rate was justified by asset pricing theory, under the assumption that climate damages are uncorrelated with overall market returns (Greenstone, Kopits, and Wolverton 2013).

Progress

Profound changes in global capital markets since the publication of Circular A-4 in 2003 make it difficult to continue to defend 3 percent as an estimate of the real return on riskless investments. For example, the average 10-year Treasury Inflation-Indexed Security rate from its inception in 2003 to the present is only 1.01 percent (figure 4). Similarly, Bauer and Rudebusch (2020, forthcoming) show that the equilibrium real interest rate has declined substantially since the 1990s. In addition, evidence from long-term real estate investments suggests that for climate mitigation, which has payoffs over very long periods of time, discount rates should be even lower than those used for shorter-lived investments (Giglio et al. 2021). On the basis of this evidence, we conclude that it is difficult to justify a 3 percent discount rate for climate investments and that there is a compelling case for a riskless discount rate of no higher than 2 percent.[18]

Although the riskless rate was originally used in the descriptive approach to discounting, it is possible that the unique risk properties of climate change and uncertainty about future interest rates make the riskless rate itself inappropriate for SCC calculations. Because SCC discount rates reflect the returns to investments that mitigate climate change, Americans would be best served by an interest rate that is associated with investments that match the structure of payoffs from climate mitigation. Specifically, capital asset pricing models recommend discount rates below the riskless rate when CO_2 mitigation investments pay off in "bad" states of the world—that

[15]This approach is recommended by the NASEM (2017) as "feasible and conceptually sound."

[16]Formally, the Ramsey equation expresses the discount rate as $r = \delta + \eta \times g$, where δ measures the pure rate of time preference, g measures the growth rate of consumption, and η captures the decreasing marginal utility of consumption. The consensus is that δ likely ranges between 0 and 2. Values for η have been estimated to range from 1 to 4 but are generally centered around 2 (Gollier and Hammitt 2014).

[17]Rates of 2.5 and 5 percent were also reported, while the Trump administration applied rates of 3 and 7 percent.

[18]A fixed rate below 2 percent does not contradict OMB (2003) Circular A-4 when long-lived benefit streams are considered: "If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent." Sunstein (2022, 6) supports this conclusion, arguing that a "decision to use a low discount rate, such as two percent, would be straightforward to defend against an arbitrariness challenge."

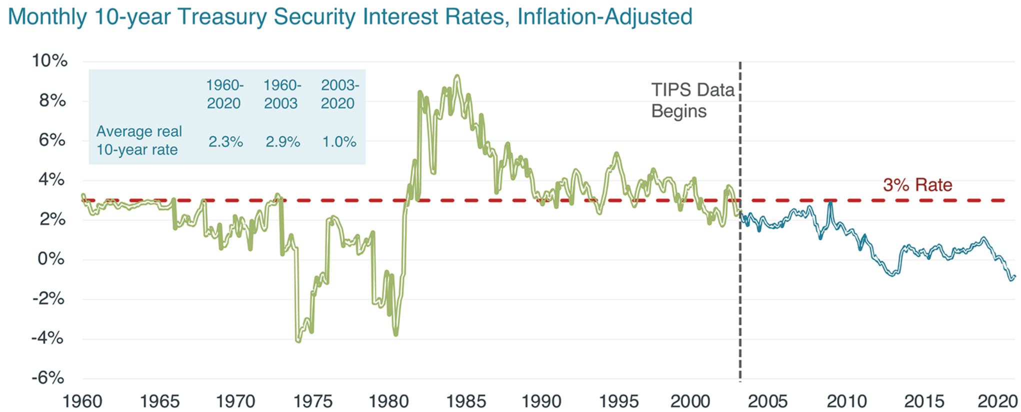

Figure 4 Monthly 10-year Treasury security interest rates, adjusted for inflation, from 1960 to 2020. Nominal interest rates, Treasury Inflation-Indexed Security (TIPS), and inflation data were retrieved from the Federal Reserve Bank of St. Louis. The TIPS rate is available starting in January 2003. Interest rates prior to 2003 are imputed by subtracting the annual inflation rate from the nominal interest rate.

is, if climate damages are likely to coincide with a slowing overall economic growth rate (Greenstone, Kopits, and Wolverton 2013). If, on the other hand, climate damages act as a tax on the economy (i.e., total damages are larger when the economy grows faster), then higher discount rates such as the average return in equity markets would be appropriate.[19]

There have also been advances in the economics of the prescriptive approach. The recent NASEM (2017) report underscored the strong theoretical justifications for Ramsey-based discounting, emphasizing in particular that extensions of the Ramsey approach can accommodate covariance between climate damages and the level of future economic growth. This is important given the risk properties of climate change, as well as uncertainty about future economic growth. However, Circular A-4 explicitly instructs agencies to use constant discounting in benefit–cost analysis (OMB 2003). In addition, because the Ramsey approach requires judgments about the value of key parameters (rather than relying on observed market interest rates), it may provide policy makers with an undesirable degree of discretion in determining the discount rate for SCC calculations.

Recommendation

Given the advantages and disadvantages of the two approaches to deriving a discount rate for SCC calculations, we recommend continuing to rely on existing asset markets to guide the

[19]The descriptive approach can be used to generate a declining discount rate, which is recommended by Gollier and Weitzman (2010), to account for uncertainty about future discount rates. This means that the descriptive approach could involve pegging the discount rate to an observed interest rate with a predetermined declining schedule, although important implementation issues remain unresolved (e.g., Newell and Pizer 2003; Cropper et al. 2014). For example, the declining discount rate literature generally assumes that climate damages are uncorrelated with the discount rate (Cropper et al. 2014), but this is limiting, given the risk properties of climate change discussed above.

discount rate choice. Moreover, given recent trends in global capital markets, we recommend a discount rate of no higher than 2 percent. When applied to the original IWG SCC framework, a discount rate of 2 percent raises the SCC to $121 in 2020 (NYSERDA and Resources for the Future 2020).[20]

Ingredient Four: Global versus Domestic Damages

Most regulatory benefit–cost analyses consider only the domestic benefits and costs of policies. However, unlike nearly every other environmental pollutant, CO_2 emissions are a global problem. That is, the damages caused by carbon emissions in the United States are felt globally, while Americans benefit equally from emissions reductions in China, the European Union, India, and Detroit. Given the global nature of the CO_2 emissions problem and to encourage emissions reduction commitments from other countries in international negotiations, the IWG used global damages to calculate the SCC. However, in 2017, the Trump administration began including only domestic damages in the SCC.

Progress

Although whether to include global or only domestic damages in the SCC is a complex economic, legal, and ethical question (Gayer and Viscusi 2016), the consensus among scientific and economic experts and international negotiators is that the SCC should include global damages (NASEM 2017). Focusing exclusively on the domestic costs of climate change may appear to put US interests first, but a growing body of evidence indicates that this is not actually the case. Nearly 90 percent of global emissions take place abroad, and history shows that when the United States accounts for the full global cost of climate change, it encourages other countries to reduce their own emissions. This can happen through other countries directly adopting the US SCC or other international actions. For example, in 2014, the US Environmental Protection Agency proposed the Clean Power Plan, a set of policies aimed at cutting carbon emissions from power plants, and within 4 months, China promised to make significant emissions reductions (Greenstone 2019). Similarly, it has been estimated that the United States was able to leverage 6.1–6.8 tons of CO_2 reductions from other countries for every ton that it pledged to cut as part of the Paris Climate Agreement (Houser and Larsen 2021).

To summarize, the global SCC helps to overcome what might be seen as a classic prisoner's dilemma (see Kotchen 2018). That is, the United States implementing a global SCC encourages other nations to do the same, lowering emissions and thus climate damages across the globe. Moreover, because of the international nature of CO_2 as a pollutant and hence the dependence of US citizens' welfare on emissions reductions abroad, a domestic-only SCC could be difficult to legally defend against an arbitrariness challenge (Sunstein 2022).

Recommendation

We recommend using global damages in calculating the SCC, even though for many regulations, it is standard to use only domestic measures of costs and benefits.

[20]This value has recently been applied across New York State agencies.

Ingredient Five: Socioeconomic and Emissions Module

As part of the SCC calculation, a baseline trajectory of economic growth and CO_2 emissions is compared with a trajectory in which one more ton of CO_2 is released. Because of nonlinearities in the relationship between emissions and climate change damages (i.e., a marginal emission causes more damages at higher temperatures), higher baseline CO_2 emissions will result in a higher SCC. In contrast, baseline economic growth affects the SCC in a number of competing ways. For example, wealthier economies generate higher emissions, which means that marginal tons do more damage and thus increase the SCC. However, wealthier countries are also better able to invest in adaptations—such as increased air-conditioning—that reduce the impacts of climate change. Changing demographics can also alter the SCC by, for example, increasing population levels and raising the share of the population at higher risk of heat-induced mortality.

2010 IWG approach

The IWG relied on five socioeconomic and emissions trajectories,[21] with four scenarios representing business as usual trajectories and one scenario assuming aggressive climate policies that dramatically reduce future emissions. The IWG calculated the SCC under all five scenarios and averaged the result, giving equal weight to each scenario. However, these scenarios were overly simplistic and lacked transparent documentation and justification for key assumptions (NASEM 2017).[22]

Progress

There has been some scientific progress in developing long-run socioeconomic and emissions projections, although this remains a challenging area for research. The IPCC and many researchers have moved toward using the Shared Socioeconomic Pathways (SSPs), which are a set of five country-level deterministic economic and demographic projections, as benchmark scenarios (Riahi et al. 2017). One advantage of SSPs is that they can be linked to the Representative Concentration Pathway (RCP) emissions scenarios, which are a standardized set of widely used global emissions trajectories (van Vuuren et al. 2011).

However, these scenarios do not systematically characterize uncertainty. In response, economists have recently developed more sophisticated modeling techniques that rely on historical data to generate probabilistic economic projections (e.g., Müller, Stock, and Watson 2019), and demographers have done the same for population (United Nations Department of Economic and Social Affairs, Population Division 2019). These empirically based projections can also be combined with expert elicitation to reflect additional sources of uncertainty (NASEM 2017), as done very recently by Rennert et al. (2021).[23]

[21]These trajectories were developed by the Stanford Energy Modeling Forum (Clarke et al. 2009).

[22]For example, they assumed that economic growth declines linearly to zero by 2300.

[23]Expert elicitation is a structured process in which multiple experts are asked to report their subjective estimates of an unknown quantity (such as future economic growth) and its probability distribution (O'Hagan et al. 2006).

Recommendation

For the socioeconomic and emissions module, we recommend either linking the SSPs and the RCPs or relying on new probabilistic projections that combine statistical methods with expert elicitation. However, if new probabilistic projections are used, we recommend that they be constrained so that they are consistent with insights from the SSP/RCP approach. For example, probabilistic future temperature changes can be constrained to fall within the range of temperature changes generated by the RCPs. Once the scientific community has been able to fully evaluate new probabilistic projections, such as those presented in Rennert et al. (2021), we recommend shifting entirely to these because of their ability to characterize uncertainty.

Ingredient Six: Valuing Uncertainty about Climate Damages

Economic theory as well as empirical evidence (e.g., the existence of the insurance industry) reveals that people dislike risk and value reductions in uncertainty. Calculating the SCC entails several sources of uncertainty, including uncertainty about future economic growth, temperature sensitivity to additional emissions, and the economic damages from a given level of climate change. However, the IWG did not account for uncertainty when valuing climate damages (effectively assigning zero value to risk); rather, it noted that this issue "demands further attention" (Greenstone, Kopits, and Wolverton 2013).

Progress

In the past decade, advances in computing have enabled researchers to make probabilistic climate change projections that account for multiple sources of uncertainty about the magnitude of climate damages. This means that it is now possible to characterize these uncertainties and incorporate them into SCC calculations. For example, Rode et al. (2021), Carleton et al. (forthcoming), and Rode et al. (2022) account for both climatological and statistical uncertainty in their estimates of climate change damages to energy consumption, mortality, and labor, respectively. A large theoretical literature shows that valuing this uncertainty when individuals are risk averse can substantially increase the SCC (e.g., Jensen and Traeger 2014; Lemoine 2021).

Recommendation

We recommend that the calculation of the SCC use standard economic theory to value the considerable uncertainty about climate change damages.[24] Failing to do so places zero value on the uncertainty around climate damage and runs counter to both individuals' demonstrated dislike of risk and basic economic principles.

[24]This should be done by accounting for risk aversion using standard parameterizations of the utility function (e.g., $\eta = 2$ in a constant relative risk-aversion utility function) from the existing literature to determine the "certainty-equivalent" value of damages under climate change (Traeger 2014). A certainty-equivalent value is computed by determining the consumption loss that society would accept as a certain outcome in place of the distribution of future uncertain outcomes.

Ingredient Seven: Equity

Economic theory shows that an additional dollar is worth more to a poor person than a wealthy person. Applying this principle to the SCC requires "equity weighting" such that a given amount of climate damages projected to occur in poorer US counties or states contributes more to the SCC than the same amount of climate damages in wealthier regions. Taking this logic one step further, damages occurring in poor countries would be given more weight than damages in wealthy countries.

2010 IWG approach

Citing theoretical and practical concerns, the IWG chose to omit equity weighting. More specifically, the IWG determined that the economic literature on equity weighting was insufficiently mature and that standard operating procedure for the US government requires separate analyses of the distributional impacts of policies, rather than incorporating distributional concerns into benefit–cost analyses (Greenstone, Kopits, and Wolverton 2013).

Progress

The same logic that justifies the use of discounting and the valuation of uncertainty over future states of the world implies that equity weights should be applied in SCC calculations; indeed, a declining marginal value of consumption is the fundamental economic concept underlying concerns about discounting, uncertainty, and equity. Therefore, the most intellectually coherent approach would be to derive equity weights from the large literature on the marginal value of consumption and apply them to spatially heterogeneous climate damage estimates.[25]

However, OMB (2003) Circular A-4 does not explicitly allow for equity weighting in benefit–cost calculations. Thus, the use of equity weighting would be a significant departure from standard US benefit–cost analysis and influence precedent across domains far beyond climate regulations, although it would not be legally infeasible (Sunstein 2022). Moreover, calculating equity weights depends on a particular specification of a utility function.

Despite the challenges to conducting equity weighting, new local-level climate change damage estimates allow the presentation of distributional impacts alongside the SCC even if equity weights are not applied in the SCC calculation itself. For example, new projected mortality risk estimates have been made for ~25,000 global regions, and these projections can be used to characterize how climate damages vary with geography, income, race, and other factors both within the United States and globally (Carleton et al., forthcoming).[26] By including this distributional information, equity considerations can inform decision-making without imposing a particular utility function.

Recommendation

We recommend that information on the distributional impacts of climate damages be presented alongside the SCC but that equity weighting not be incorporated into the SCC unless

[25]Standard parameterizations of utility function curvature (e.g., $\eta = 2$ with constant relative risk-aversion utility) can be used to derive equity weights.
[26]See figure S3.

there is a review and overhaul of Circular A-4. Such an update to Circular A-4 could allow for full consideration of equity implications across multiple domains beyond climate change.

An Implementation Pathway for an Updated SCC

We have argued that returning the SCC to the scientific frontier requires using an updated climate model, a new set of damage functions, a lower discount rate, and consideration of global damages. Updates to the other three SCC ingredients would be valuable, but they involve judgment calls that depend on several factors, including scientific and/or economic evidence and political considerations. However, we believe that there is an especially strong analytical (and perhaps legal) case for valuing the substantial uncertainty around climate damages.

The integration of these ingredients to create an improved SCC requires choosing an implementation pathway. One approach would be to update each of the seven SCC ingredients within the three existing IAMs, wherever possible, and to then use these models to produce new SCC distributions. While at first glance this approach may be appealing, there are conceptual and practical challenges to incorporating new damage functions into the existing models. These challenges include lack of consistency between empirically founded, sector-specific damage functions and IAM damage functions, which makes it difficult to know which sectors in the current IAMs to replace with new empirically founded evidence; low spatial resolution in existing IAM damages, which makes it impossible to characterize inequities; inconsistent treatment of adaptation across models, which makes it difficult to match adaptation assumptions with empirically founded approaches to estimating adaptation; and legal risks that arise due to an inability to fully remove the ad hoc assumptions in old models (Sunstein 2022). Additionally, these three IAMs prevent the IWG from fully implementing two key ingredients: valuation of uncertainty and equity.[27]

Thus, we recommend a second approach that would return the SCC to the frontier of understanding and ensure its legal durability: the construction of a new SCC framework. Such a change is also consistent with the NASEM (2017) recommendation for a new IAM. From a practical standpoint, the form of this new SCC framework will depend on whether the current OMB Circular A-4 remains in force. In the remainder of the article, we first describe an implementation pathway for building a new SCC that is consistent with the current version of Circular A-4. We then summarize how this pathway could evolve under an updated Circular A-4.[28]

Building a New IAM under the Current Circular A-4

Under this pathway, we recommend that a new IAM be built that directly follows the recommendations above for each of the seven SCC ingredients. Such a new framework is currently under development by the Climate Impact Lab (CIL; Nath et al. 2022).[29] The CIL combines SSP projections (and can accommodate others), high-resolution climate projections for multiple

[27]These issues are discussed in detail in the appendix.
[28]See the appendix for details.
[29]The CIL is a collaboration of climate scientists, economists, and computational scientists building an empirically based SCC. We are both core members of the CIL. More information about the CIL is available at http://www.impactlab.org/.

RCP emissions scenarios, and comprehensive historical data sets to estimate sector-specific, flexible, globally representative damage functions that capture heterogeneity across ~25,000 regions and account for adaptation and its costs. It then applies the FAIR climate model and a range of valuation and discounting approaches to transform these damage functions into a distribution of SCC estimates while accounting for and valuing multiple sources of uncertainty. Under this pathway, the distributional consequences of climate change would be reported alongside the SCC, enabling equity considerations to play a role in decision-making even if equity weights are not applied to the SCC itself.

This approach has strengths and weaknesses. One of its strengths is that all of the recommendations for the seven SCC ingredients can be adopted. Another important strength is that it allows for characterizing the distributional effects of climate policies for locations and demographic groups within and beyond the United States.

However, a weakness of this approach is that damage functions meeting the three criteria discussed above are not available for all sectors affected by climate change. Therefore, although this new IAM will become more complete as science and economics advance, in the medium term, the resulting SCC will be based on incomplete damages. However, this challenge would not be solved by using the existing IAMs because difficult-to-quantify damages remain absent or overly simplistic in these models (Kopp and Mignone 2012).[30] For example, in FUND, energy demand alone accounts for ~90 percent of the SCC (Diaz 2014), suggesting that in practice, many "modeled" sectors remain unquantified. DICE includes a 25 percent damage adjustment for nonmonetized impacts based on "judgmental assessment" (Nordhaus and Moffat 2017). In PAGE, catastrophic risks arise through an arbitrary damage discontinuity. In contrast, building a new IAM based directly on the most credible sector-specific empirical evidence will make it straightforward to add new sectors to increase the comprehensiveness of the SCC. Similarly, updates to other modules, such as the climate model, can also be easily accommodated.

A second weakness of this approach is that the practical constraints of Circular A-4 lead to some conceptual inconsistencies. In particular, combining constant discounting (as recommended above for ingredient three) with the valuation of uncertainty (as recommended above for ingredient six) means that different marginal utilities of consumption are accounted for when valuing different states of the world in a given time period but not across time.

Despite these constraints, our conclusion is that a new SCC framework should be based fully on empirical evidence that meets modern standards. While this approach may initially omit certain categories of damages, existing results suggest that even a partial accounting of empirical sector-specific damages is likely to raise the existing US SCC,[31] particularly if discount rates are updated and uncertainty is valued. Moreover, we believe that the SCC's legal durability would be enhanced because this approach both reflects scientific advances over the past dozen years and is built to accommodate future advances.

[30]See the appendix for details.
[31]See figure 1.

Building a New IAM under an Updated Circular A-4

If OMB Circular A-4 were updated to allow for more flexibility in the valuation of climate change damages, endogenous discounting (ingredient three) and the valuation of equity (ingredient seven) would be feasible. If such updating occurs, we recommend that a new IAM be built that follows the exact SCC framework described above but that replaces constant discounting and no equity weighting with a flexible valuation approach that includes Ramsey discounting, equity weighting, and uncertainty valuation.[32] Under either the current or an updated Circular A-4, building a new IAM that follows these recommendations will deliver a transparent, internally consistent, and scientifically robust set of SCC estimates that could accommodate new research as it evolves.

Conclusions

The Biden administration is expected to release an updated set of SCC estimates in 2022. Written before these updates were released, this article has presented a recipe for returning the SCC to the frontier of climate science and economics; it can also be used as a guide for understanding and assessing the resulting Biden SCC. For the most part, our recommendations are consistent with the conclusions on how to update the SCC reached almost 5 years ago by NASEM (2017), with key differences due largely to research advances since its publication.[33]

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[32]We discuss the theoretical basis for this approach, its variations, and its strengths and weaknesses in the appendix.

[33]See the appendix for specific differences in the recommendations.

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