Journal of Benefit-Cost Analysis (2023), 14: 2, 191–204
doi:10.1017/bca.2023.31

CAMBRIDGE UNIVERSITY PRESS

ARTICLE

Seven Recommendations for Pricing Greenhouse Gas Emissions

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Keywords: SC-GHGs; discounting; uncertainty analysis; RIA; EPA

JEL classifications: D61; H43; Q51; Q54; Q58

Abstract
The social cost of greenhouse gases is important in many regulatory impact analyses. However, calculations of the social cost of greenhouse gases are highly complex and periodically revisited. We offer seven recommendations to improve current estimates. These include recommendations to use both country-level and global measures of the social cost of greenhouse gases, to use country-specific values for monetizing climate damages, to represent uncertainties by reporting distributions instead of using only central values, and to conduct a temporal distributional analysis that shows the magnitudes of climate damages across generations. We also provide recommendations for the discount rates that should be used when estimating the social cost of greenhouse gases, and the appropriate discount rates for regulatory impact analyses that include the social cost of greenhouse gases.

1. Introduction

Political and institutional barriers constrain the implementation of economy-wide taxes on greenhouse gas (GHG) emissions in the United States (Aldy *et al.,* 2022), leading government agencies to rely on regulatory policies that are analyzed using shadow prices in Regulatory Impact Analysis (RIA). This article provides seven recommendations that the U.S. Environmental Protection Agency (U.S. EPA) should incorporate into revised shadow price estimates reported in an external review draft titled "Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances" (U.S. Environmental Protection Agency, 2022) (hereafter, EPA-ERD). The EPA report proposes new estimates for the social costs of carbon (SC-CO2), methane (SC-CH4), and nitrous oxide (SC-N2O), collectively, the social cost of greenhouse gases (SC-GHGs). These proposed

SC-GHGs provide the present value of the stream of global damages through the year 2300 caused by a one-ton increase in global GHG emissions in a given period. Final estimates will be published sometime later this year.

The proposed SC-GHG estimates reflect methodology changes from past practices, including the following:

1) A modular integrated assessment (IAM) model is used to simulate climate-economy interactions, as proposed in a report in 2017 by the National Academy of Science (NASEM, 2017).
2) Three damage functions are independently used to estimate climate damages: one based on sectoral damages at a subnational scale (DSCIM); one based on sectoral damages at a country scale (GIVE); and a third based on a meta-analysis of the existing literature that does not differentiate damages among sectors. Estimates from these damage functions are combined into an equally weighted average that provides central values for SC-GHG estimates for use in policy analysis.
3) The EPA-ERD reverts to the Obama administration's practice of covering worldwide climate damages in the SC-GHG estimates (departing from the Trump-era practice of counting only damages directly affecting the United States). Estimates produced at subnational and national scales are aggregated to the global level.
4) The EPA-ERD adopts a Ramsey discounting formula in the calculation of SC-GHG estimates that treats the growth rate component as stochastic, giving a discount rate schedule that declines over time.
5) The discount rates chosen for the initial calibration of the Ramsey formula, 1.5%, 2%, and 2.5%, are significantly lower than the constant rates used in previous administrations (2.5%, 3%, and 5% from 2010 to 2016; 3% and 7% from 2017 to 2020).

The first two of these methodology choices reflect scientific advances, while the others incorporate normative judgments. Some comparisons can illustrate the relative impact of these factors. For example, measured in $2020, the central value for the Trump administration's SC-CO2 estimate in 2020 at a 3% discount rate equaled $7/metric ton; the Obama administration's estimate at a 3% discount rate using the same climate-economy model equaled $51/metric ton. In other words, holding all else constant, changing the scope of the damages recorded in SC-GHG estimates from the USA to the world increases the value of the SC-CO2 by 7.3 times. As another example, the central value for SC-CO2 estimates for the year 2020 in the EPA-ERD ranges from $120/metric ton for a 1.5% discount rate to $340/metric ton for a 2.5% discount rate. That is, reducing the discount rate by 1 percentage point increases the 2020 value of the SC-CO2 by over 2.8 times, demonstrating the sensitivity of SC-GHG estimates to discounting over several centuries. In contrast, the highest SC-CO2 estimate for 2020 among the three damage functions is only 9% to 19% greater than the lowest estimate, holding the discount rate constant.[1] In sum, normative judgments about the geographic scope for recording damages and choices about the social discount rate significantly affect the estimates of SC-GHGs.

In this article we offer seven recommendations that broadly consider the normative perspectives and methodology choices underlying the complex SC-GHG calculation. We believe that transparency about the rationales and uncertainties underlying SC-GHG estimates is the best approach for informing policymakers and the public about the value of reducing

[1] Data comes from Tables ES.1 pp. 3 and 3.1.1 pp. 67 in the EPA-ERD.

https://doi.org/10.1017/bca.2023.31 Published online by Cambridge University Press

climate risks. The philosophy guiding our recommendations is in the spirit of the 10-tips guide published in the JBCA to help inform consumers about RIA methodology (Dudley *et al.*, 2017).

2. Recommendation 1. Use both global and domestic measures of the social cost of greenhouse gases

Both global and domestic SC-GHGs are policy-relevant. Providing both estimates will increase transparency about the underlying analysis while also providing clarity about who receives the benefits, will foster policy discussions about fairness and equity, will furnish agencies with the flexibility to prepare analyses consistent with their statutory mandates, and will provide important distributional information to support international negotiations. We believe the emphasis given to the use of the domestic or global estimate depends on the context of the analysis and the basic principles of policymakers.

The exclusive focus on the global SC-GHG presumes that U.S. policymakers are indifferent to whether climate-control benefits occur in the USA versus elsewhere in the world – a perspective inconsistent with basic notions of national interest and the focus of U.S. laws, such as the Clean Air Act, that specify that relevant "benefits" are those to the "Nation" and not the world. It is also inconsistent with President Clinton's 1993 Executive Order on regulation, which is still in effect, that seeks a regulatory system that serves the American people. Moreover, development and use of a domestic SC-GHG would increase transparency by providing information about reductions in domestic GHG-related damages from climate change initiatives to members of Congress, and to U.S. taxpayers and voters, who have a right to know the projected effect of policy decisions in the USA (Fraas *et al.* (2016); Gayer and Viscusi, 2016).

Presenting a disaggregated picture of climate benefits is also consistent with commitments to consider the equity impacts of environmental policies. An exclusive focus on the global SC-GHGs is at odds with President Biden's Modernizing Regulatory Review memorandum calling for more distributional analysis regarding "disadvantaged, vulnerable or marginalized communities" in the USA. The development of domestic SC-GHG estimates is a prerequisite for being able to monetize the impacts of GHG policies on such communities in the USA.

We agree with EPA that global SC-GHG estimates would help to promote future international cooperation and indicate the future scale of international cooperation that fighting climate change requires. But international cooperation and reciprocity must be appraised in terms of emissions reductions – that is, which countries can be expected to cut their emissions, by how much, and by what dates due to U.S. action – and an objective look at the likelihood of projected cuts. After all, most countries are failing to meet their commitments under the 2015 Paris Agreement, which did not establish legally binding emissions limits. Longstanding practice in regulatory analyses has been to incorporate only those changes in behavior that are required by current law. In the international context, a comparable approach would credit only reductions associated with binding agreements, not goals or pledges.

In its proposed revision of global SC-GHG estimates, EPA provides estimates for climate impacts physically occurring within the USA for a limited set of damage categories.[2] These

[2] The categories are health, energy, agriculture, and coastal regions for the GIVE and DSCIM damage functions. The DSCIM model also includes labor productivity.

https://doi.org/10.1017/bca.2023.31 Published online by Cambridge University Press

estimates are accompanied with the caveats that they only cover a subset of damages, do not capture spillovers or indirect effects, and are not equivalent to benefit estimates for US citizens and residents. These caveats are given as major reasons for presenting only global damage estimates.

These arguments are unpersuasive. Estimated damages at regional and country scales are aggregated into global estimates, so the global estimates have the same sectoral limitations as the damage estimates they are derived from. The EPA is confident enough in the aggregated estimates to equally weight them with the damage estimates derived from meta-analysis to provide a combined estimate for policy analysis (EPA-ERD, pp. 81). Moreover, country-level damage aggregates in the USA are discounted using a discount rate derived from U.S. market data, so there is a better match between the willingness to pay for climate damages and the discount rate used to convert them into present values in the USA than in other countries, where the U.S. rate is also applied. (discussed under Recommendation 4 below). Owing to this mismatch, SC-GHGs computed at the country level in the USA are likely to be more accurate than global damage estimates, given the sensitivity of SC-GHG estimates to the discount rate.

A rich set of economic and environmental data are available to support improved estimates of climate damages to the USA. As the science improves further, we would support developing and reporting damage estimates for states, regions, and counties in the United States. Modeling at regional scales could be "soft-linked" into the IAM – an increasingly common approach for combining complex models in the energy and climate areas (Krook-Riekkola *et al.,* 2017).[3] A scientific advisory panel to the EPA recommended soft-linking as an option for incorporating disaggregated spatial environmental information into the EPA's SAGE model (U.S. Environmental Protection Agency, 2017).

Looking to the long run, developing both domestic and global SC-GHG estimates is likely to promote stability in analytic practices at EPA and other agencies, reducing the likelihood of disruptive whipsawing of GHG policy analyses across administrations. Given the long-term nature of climate change policies, it is essential that the regulatory analyses provide data that will be of continuing policy relevance.

3. Recommendation 2. Use country-specific values for assessing nonmarket benefits

Analysts should evaluate the nonmarket benefits like mortality risk reductions using the willingness to pay of the populations in the affected countries. This makes the valuation of nonmarket benefits consistent with the valuation of the monetized portion of climate damages, which reflect country attributes as measured in GDP changes. The most widely developed estimates of international differences in the value of a statistical life (VSL) assess how the VSL varies with income. The EPA-ERD correctly recognizes that using the VSL in the USA for benefit transfer purposes without adjustment for income differences is not appropriate.

The value of mortality risk reductions is the largest benefit category in the SC-GHGs for the models that explicitly compute them.[4] The value of the mortality reduction benefits

[3] Soft-linking uses an iterative process for combining models that are computationally challenging even when standing alone. The models are solved with feedbacks between them, until convergence is achieved to key variables such as prices, quantities, and damage estimates.

[4] EPA-ERD Table 3.1.4, pp. 76. For the DSCIM damage function, health damages account for 77% of SC-CO2. For the GIVE damage function, health and agricultural damages each account for about 47% of total damages.

should reflect the willingness to pay of the residents in the countries where they occur. Preferences for risk reduction will differ across countries for a variety of reasons, such as social norms, religion, availability of health care, and income. The effect of income on the value of mortality risk reduction is the principal characteristic identified by the economics literature. As with other normal goods, the valuation of mortality risk reductions is an increasing function of income. If there is a positive income elasticity of the VSL, the mortality cost reductions in lower-income countries will be accorded a lower value.

The EPA uses an income elasticity of 1.0. The EPA cites a variety of references supporting a positive income elasticity. Some of these references are judgmental assessments or reports of recommended practices lacking empirical evidence. While some of the cited references explicitly advocate income elasticity values other than 1.0, a couple of the studies report empirical estimates of an international income elasticity of the VSL equal to 1.0.[5]

In effect, the VSL accorded to mortality risk reductions in poorer countries will be a value that is proportionally lower than that used for the USA. Some observers have criticized income-adjusted VSL estimates for devaluing the lives of those outside the USA. This criticism is not warranted because a country's income status influences its expenditure priorities. While there is disagreement over the recommended income elasticity, the EPA's approach of applying a positive income elasticity to the benefits transfer of U.S. VSL estimates internationally is sound.

4. Recommendation 3. In the near term, adopt constant rates of 3% and 5% for computing SC-GHGs. Also use these rates to calibrate stochastic Ramsey discount rates

This recommendation gives four discount rate cases, ranging from lowest (stochastic Ramsey rate at 3%) to highest (constant discount rate at 5%). The constant rates are a return to the Obama-era rates. The 3% and 5% rates are quite conservative, given credit constraints in U.S. debt markets that many consumers use to smooth consumption. The stochastic Ramsey rate declines over time and is consistent with the point of view that declining discount rates are appropriate for intergenerational discounting.

4.1. Selecting target consumption rates of discount

Based on the evidence presented below, real consumption discount rates of 3% and 5% are quite conservative, given credit constraints in U.S. debt markets that many consumers use to smooth consumption, and are even less representative of consumption discount rates for low- and middle-income countries. However, to avoid an abrupt change in practice, we recommend that EPA use the 3% and 5% constant rates in the near term – a return to the practice of the Obama administration. Obama/IWG adopted 5% in part to provide that some "…account should be given to the discount rates revealed by their [consumer] behavior." (IWG, 2010, p. 23).

[5] Viscusi and Masterman (2017) report an average international income elasticity outside the U.S. of 1.0 based on revealed preference evidence, and Masterman and Viscusi (2018) report overall global income elasticities ranging from 0.94 to 1.05.

https://doi.org/10.1017/bca.2023.31 Published online by Cambridge University Press

The EPA-ERD selects a target consumption rate of discount of 2% bounded with a range from 1.5% to 2.5%. EPA justifies this range due to the substantial and persistent decline in the average real return to Treasuries in recent decades. However, real 30-year average Treasury rates were greater than 3% through 2013 (Figure 1). The 30-year average only dropped below 3% with the marked decline in rates after the Great Recession. Figure 2. presents 10-year Treasuries over the most recent 30-year period. The highlighted areas show periods when the Federal Reserve was lowering the federal funds rate – the traditional Federal Reserve monetary policy to lower interest rates to address a weakening economy. After a recovery from the DotCom bust and 9/11, the real interest rates on 10-year Treasuries

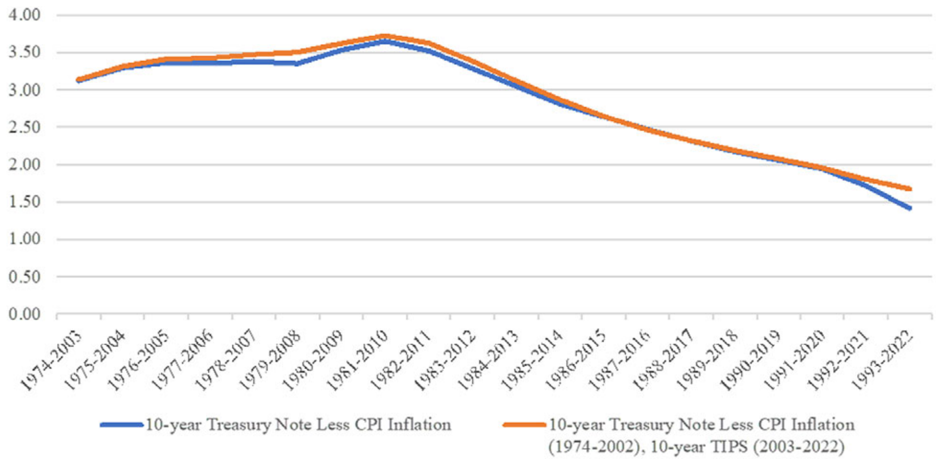

Figure 1. *30-Year Average 10-Year Real Treasury Rates.*
Source: Preamble to March 2023 Proposed Revision to Circular A-4.

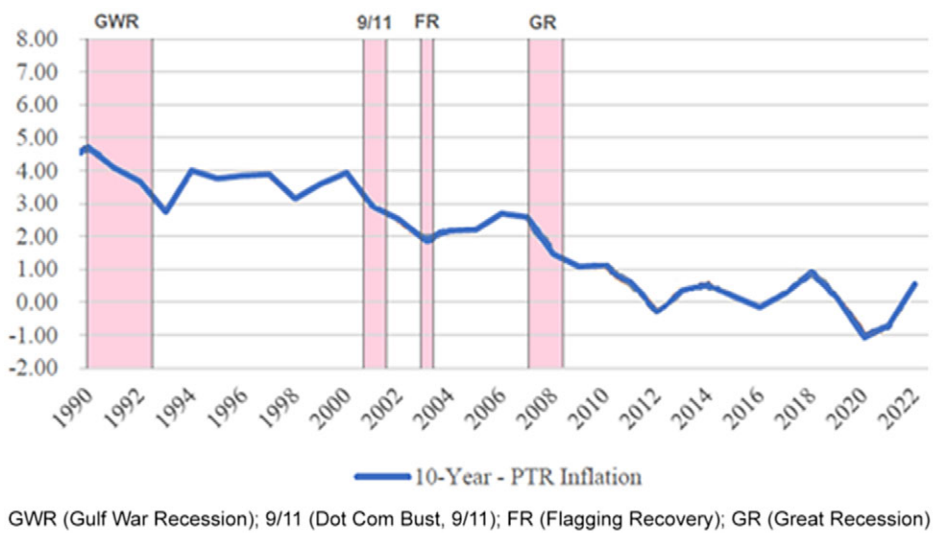

Figure 2. *Measures of 10-year Real U.S. Treasury Rates.*
Source: Preamble to March 2023 Revision to Circular A-4.

https://doi.org/10.1017/bca.2023.31 Published online by Cambridge University Press

trended up from 2% to close to 3% before the Federal Reserve moved to address the Housing Market Crash beginning in September 2007 – the crisis resulting in the Great Recession. The decline following 2007 is directly linked to the Federal Reserve's "quantitative easing" policy – an unusual policy by historical standards – which operated to keep returns on Treasury notes artificially low (Kashyap and Stein, 2023). In any event, interest rate behavior in the most recent three decades is not more relevant than interest rates from earlier historical periods, given the long-term forecasting horizon for SC-GHG estimates.

EPA also cites several studies that survey economists and other researchers in the climate area, that is, Drupp *et al.* (2018), Howard and Sylvan (2020), and Pindyck (2019). However, the means and upper bound estimates of these surveys are generally higher than the target discount rates that EPA has proposed to use for its SC-GHG estimates.

The larger issue is that the market for 10-year Treasury notes is more relevant for infrastructure finance than for regulatory evaluation (Krutilla and Graham, 2023). In contrast to public investments, the incidence of regulatory benefits and costs falls on some combination of companies that undertake capital investments for regulatory compliance, their customers, and the broader U.S. population. The market for 10-year Treasury notes is not an appropriate way to measure the discount rates of households whose consumption smoothing decisions are affected by climate regulations. Few individuals invest in 10-treasury notes (CEA, 2017); foreign governments, institutional investors, and the social security trust fund hold the largest share.

Individuals who do hold 10-year Treasuries are likely to be higher income. Data from the Survey of Consumer Finances show that very few low-income households hold securities with risk/ return/liquidity profiles like 10-year Treasury notes. In addition, they maintain only minimal balances in their transaction accounts – checking and savings accounts and the like – keeping only what is necessary for monthly expenses and small, unexpected expenses.

Data from the Federal Reserve's most recent 2019 Survey of Consumer Finances indicate direct bond holdings are zero for more than 99 percent of families with incomes below the 60th percentile. Holdings of similar financial instruments are quite rare. Holdings of certificates of deposit are 2.7 percent, 5.7 percent, and 8.0 percent for the first, second, and third quintiles of family income. Holdings of savings bonds are 2.3 percent, 5.5 percent, and 7.7 percent for these three quintiles of families. Holdings of "pooled investment funds" are 2.1 percent, 3.6 percent, and 6.2 percent for these quintiles. Even retirement accounts, regardless of the type of financial assets included in them, are uncommonly held. For the first, second, and third quintiles of family income, 10.7 percent, 32.8 percent, and 53.7 percent of families have retirement accounts.

The EPA-ERD points out that credit-constrained consumers are likely to hold high interest rate debt and explains (pp. 53):

"This behavior may reflect rational intertemporal preferences, or it may reflect other factors such as present bias, lack of financial literacy, and other distortionary effects of poverty. …Nevertheless,… the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior." EPA's selection of target discount rates, however, does not give any weighting to revealed consumer behavior.

Field experiments have elicited consumer consumption discount rates directly. Nominal discount rates for U.S. military personnel making choices about compensation packages varied between 10% and 54% (Warner and Pleeter, 2001). Other research reports implicit discount rates for used car buyers ranging from 2.8% to 16.9% (10th to 90th percentile)

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(Busse *et al.,* 2013) with a mean implicit discount rate of 13% (Allcott and Wozny, 2014). Hausman reports a discount rate of 20% for consumers purchasing energy-using durables (Hausman, 1979).[6]

Justifying regulations using social discount rates below consumers' marginal rates of time preference has distributional implications (Miller, 2015). Energy efficient appliances and vehicles that do not yield enough fuel bill savings to compensate for forgone current consumption, as consumers evaluate this tradeoff, burden consumers. Such regulations can incentivize consumers to delay new purchases, or to shop in secondary markets for used products at marked-up prices due to regulatory-induced demand shifts (Davis and Knittel, 2019). Raising the price of energy-derived products places singular burdens on low-income consumers. These effects go against the distributional equity objectives promoted in President Biden's Modernizing Regulatory Review memorandum.

4.2. Ramsey social discount rate equation

To conduct BCA over a temporal horizon of several hundred years requires the use of an intergenerational discount rate. Devising an intergenerational discount rate that appropriately balances current and future generation welfares is profoundly challenging (Pearce *et al.,* 1994). For example, a zero discount rate would justify virtually unlimited sacrifice of current-generation income to finance benefits for future generations. Non-zero but low discount rates, for example, 1%, will place significant weight on far future generation benefits that are especially uncertain, given the limited capacity to forecast climate damages so far in the future. On the other hand, higher positive discount rates will accelerate the cut-off period in the future after which the present value of future benefits is insignificant, placing too much weight on current generations at the expense of future generations.

The Ramsey discounting formula is often used for intergenerational discounting.[7] The first order conditions for consumption smoothing from a standard economic growth model give the Ramsey discounting formula: $r = \delta + \eta g$, where r is the consumption discount rate, δ is the pure rate of time preference (the utility discount rate), η is the elasticity of marginal utility of consumption, and g is the growth rate of consumption. The η term can be regarded as a distributional weight that raises the discount rate when $g > 0$; that is, the term ηg discounts future welfares when future populations have higher per capita incomes and therefore lower marginal utilities of consumption. The EPA-ERD calibrates the δ and η parameters so that the average certainty-equivalent discount rate over 10 years matches a short-term consumption rate, measured as the rate of return on 10-year Treasury notes.[8] The growth rate g is taken as stochastic, endogenizing the correlation between damage estimates and economic growth, and causing the discount rate to decline over time.

The strengths of Ramsey's equation include an intuitive rationale for intergenerational welfare comparisons, and the simplicity of the basic notion that future consumption can be increased by investing the savings obtained by deferring current consumption. The decline in the stochastic Ramsey rates over time is consistent with the view that declining discount rates are appropriate for intergenerational discounting.

[6] The discrepancy between these discount rates and those assumed in the RIA is one explanation for the "energy efficiency paradox." See Helfand and Dorsey-Palmateer (2015).

[7] This approach is based on a seminal paper by Frank Ramsey in 1928 (Ramsey, 1928).

[8] There is also a second calibration condition governing the shape of the certainty equivalent rate over time.

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The Ramsey model also has limitations. The economic growth literature considers multiple extensions to the standard Ramsey economic growth model, and these give different first-order conditions for consumption smoothing than the standard Ramsey equation, for example, Krutilla and Reuveny (2004, 2006) and Xepapadeas (2005). The literature on endogenous discount rate formation also gives modifications of the standard Ramsey consumption smoothing condition, for example, Poulos and Whittington (2000). The standard Ramsey model does not include measures of wealth in the utility function, such as environmental amenities or health states (Krutilla and Reuveny, 2002; Viscusi and Evans, 1990). This absence distorts intergenerational welfare comparisons. The neoclassical Ramsey model also leaves out externalities that impact future welfare (Stern *et al.,* 2022).

Applying the Ramsey model is more complicated than estimating the social rate of time preference using interest rates from market data or surveys. OMB notes in its proposed revision to Circular A-4 (p. 77) that "explicit modeling of discount rates has a firm grounding in the underlying economics of welfare analysis*, when the model is designed to well-approximate relevant preferences and behaviors* (emphasis added). If you take a Ramsey approach to discounting, a number of assumptions need to be made to inform the selection of parameter values." The calibration exercise noted above in the EPA-ERD's application of the Ramsey rule is an example. As a result, OMB's proposed A-4 revision would require agencies considering the use of the Ramsey model to confer with OMB before proceeding.[9]

4.3. A declining discount rate can result in temporal inconsistencies over long time horizons

The declining discount rate schedule obtained by calibrating a stochastic growth rate within the Ramsey formula can lead to temporal inconsistencies over long time horizons, giving a mismatch between the within-generation intertemporal preferences of the future generation and the forward intertemporal preferences of the future generation that the current generation assigns to them (Viscusi, 2022; Viscusi *et al.,* 2019). The declining discount rate reflects the weighting by current generations of impacts on future generations. The decisions made by the current generation may have different effects, or effects that occur at different times in the future, relative to the choices of future generations. Future generations will likely live longer – for example, the generation born in the USA in 2080 might live to 85 or even 90 years, given the Congressional Budget Office (CBO) estimates longevity of 81 years by 2051 (CBO, 2022). Within that future generation, use of a declining discount rate would place a greater weight on benefits in the latter part of the generation than in the early years. The future generation may prefer a different trajectory of benefits that is more front-loaded within that generation than would result from the forward-looking preferences associated with the declining discount rate. See Birdsall and Steer (1993) and Wildavsky (1988).

Our recommendation is to use both constant discount and declining discount rates, given that no alternative is ideal, and intergenerational discounting poses philosophical questions.

[9] A survey of discounting experts found that most experts do not apply the assumptions embedded in the Ramsey formula when advising on social discount rates, suggesting factors beyond the basic Ramsey formula are important. See Drupp *et al.* (2018).

https://doi.org/10.1017/bca.2023.31 Published online by Cambridge University Press

5. Recommendation 4. In the long-run, develop country-specific discount rates for intergenerational discounting

The assessed benefits of GHG policies in different countries should reflect the preferences in these countries, including rates used for intertemporal tradeoffs. Making the discount rates country-specific is consistent with the monetization of benefits, which are based on country-specific values. The vast majority of global consumers does not have access to the global capital market, and the local credit market conditions are likely to be as diverse as local climate effects. Country-level discount rates are more accurate than assuming the U.S. discount rate is representative of a global average. The consumption discount rates in low- and middle-income countries are likely to be significantly higher than those in the United States, where incomes are higher and credit constraints are relatively less binding. Policy analyses in some high-income countries use discount rates of 7–8%, and many low-income countries use discount rates in the 12% to 15% range (Campos *et al.,* 2015).

EPA adopts a single global social discount rate for intergenerational discounting using only U.S. data. Yet, the vast majority of global consumers does not invest in 10-year Treasury notes, or have access to the global capital market. Many consumers in low-income countries transact in markets lacking formal financial institutions (Banerjee & Duflo, 2008). Even when financial institutions exist, the supply of credit can be limited, especially to low-income consumers, and lack of competition for financial services can lead to predatory lending practices. These factors raise consumer discount rates. Banerjee and Duflo (2008) find that discount rates for both low- and middle-income consumers in less developed countries are about 4% per month.[10]

Discount rates for lower income classes in low- and middle-income classes are often related to local conditions. For rural populations in Ethiopia, subjective discount rates rise/fall by 17% for a 10% loss/gain to income occasioned by droughts/high rainfall (Di Falco *et al.,* 2019). In other words, discount rates are endogenously related to the local effects of climate change. Mortality risks in six low-income countries raise discount rates. The median subjective discount rates vary from 38% to 45% on an annual basis over a five-year planning horizon (Poulos & Whittington, 2000).

Country-specific discount rates have been estimated in Europe for benefit–cost analysis of projects financed from structural adjustment funds (Florio & Sartori, 2013). As a longer-term project, consumption discount rates should be estimated in every country with damage estimates that enter global SC-GHG estimates. Country-level discount rates should be used with country-level growth rates and damage estimates to estimate country-specific SG-GHGs. This would make the discounting part of the economic evaluation internally consistent with the use of country-specific values for generating and valuing physical damage estimates. Undertaking this task may seem daunting but should be considerably less difficult than estimating local and country-level damages, as is done using the DSCIM and GIVE damage functions. As explained in the introduction, the pay-off of improving discount rate estimates is high, given their impact on the magnitude of SC-GHG estimates.

[10] These two groups differ in that that low-income consumers may not have access to formal financial institutions, while middle income consumers may have access to banks or cooperative financial services.

https://doi.org/10.1017/bca.2023.31 Published online by Cambridge University Press

6. Recommendation 5. For discounting in climate rules, adopt a two-step procedure that first annualizes fixed investment costs using the social cost of capital, and then discounts benefits, operating costs, and the annualized fixed cost streams using the consumer's rate of time preference

The effects of climate regulations on both consumption and capital formation need to be addressed consistent with using a shadow price of capital. For the short term, the recommended SOC rate is a 7% real rate of interest. In the long run, sector-specific rates of return on capital should be developed, given that risks and returns differ among different sectors impacted by regulation. For the second stage, CDRs of 3% and 5% are recommended as conservative estimates for consumer discount rates.

OMB's Circular A-4 states that "the analytically preferred method of handling temporal differences between benefits and costs is to adjust all the benefits and costs to reflect their value in equivalent units of consumption and to discount them at the rate consumers and savers would normally use in discounting future consumption benefits" (OMB, 2003). The "shadow price of capital" is used to convert investment costs into consumption equivalents. Appendix A2 in the EPA-ERD "Consumption Rate of Interest and Integration into Benefit–Cost Analysis" develops a formula for the shadow price of capital that is consistent with the OMB's recommended methodology (EPA-ERD, pp. 112–115).

Kolb and Scheraga (1990) show that annualizing investment costs using the SOC, and then discounting benefits, operational costs, and the annualized capital costs using a CDR is consistent with using a shadow price of capital. This method is understandable and tractable to implement.

The Kolb/Sheraga method is particularly apt for the analysis of environmental regulations. It assumes that investment costs are exclusively in the form of displaced private capital, which fits the common scenario that companies incur capital investments to meet regulatory requirements. Companies also incur operational costs for running capital equipment, or from process adjustments in response to regulatory requirements, for example, boiler maintenance, fuel-switching, and the like. The Kolb/Sheraga method assumes operational costs are passed onto consumers, which is a reasonable assumption.

We encourage the EPA to follow this tractable approach. In the short term, 7% would be a reasonable SOC for annualizing capital costs. Estimates over the last 50 years for the annual rate of return to capital have been remarkably stable, with the rate centering around 7 percent (CEA, 2017, p. 10). In the longer term, sector-specific rates should be developed – a practice used by the French government. These rates will reflect risk premia (Damodaran, 2022). Sector-specific rates are likely to fall in the range of 5 to 10%. As explained above, conservative CDRs to implement the second stage would be 3% and 5%.

7. Recommendation 6. Provide probabilistic uncertainty analysis

Uncertainties around input parameters should be traced through to SC-GHG estimates. Distributions for the SC-GHG estimates should be reported for use in RIAs.

The EPA-ERD represents uncertainties as distributions for uncertain input parameters like population size, economic growth, discount rates, surface temperatures, and the like. However, it does not report how the uncertainties associated with the input distributions trace through to distributions of the SC-GHG estimates themselves, except for one illustrative year – 2030. Given the input uncertainties documented in the EPA-ERD, SC-GHGs should not be presented as central values for the years beyond 2030.

There are several options for better representing uncertainties in the estimates of GHGs. The estimates could be presented as distributions for use in Monte Carlo simulation. Combined with distributions for other uncertain parameters, like concentration-response coefficients for PM2.5, this would make Monte Carlo standard in RIA.[11] Alternatively, quintiles or quartiles of the SC-GHG estimates from an integrated distribution could be developed. In all cases, presentation of distributions should include lower bound values as well as upper bound estimates.

8. Recommendation 7. Conduct a temporal distribution analysis

This distributional assessment should separately report the fraction of the SC-GHG value from the present to 2100; from 2101 to 2200; and from 2201 to 2300. The uncertainty range for SC-GHG estimates should be displayed in each of these time intervals.

Presenting a separate assessment of SC-GHG values occurring at different points in the future would increase transparency, indicating how uncertainties are distributed over different time periods. This distributional representation would reveal the importance of benefits farther in the future relative to those closer to the present, allowing the public to see how the benefits are distributed among different generations. Knowledge of the benefits of GHG emissions reductions falling on the current generations is policy-relevant. The public bearing the costs of regulations is entitled to know the benefits of GHG reductions realized by the current generation and by future generations.

9. Concluding remark

Estimating the economic cost of global damages requires judgments about valuation, the representation of intergenerational tradeoffs, and the appropriate reporting format for policy analysis. This article adopts the view that transparency about normative perspectives, rationales, and uncertainties associated with SC-GHG estimates is in the public interest. As such, we have developed seven recommendations that will better inform the public and decision-makers about the value of reducing climate risks. These include recommendations to report both country-level and global damage estimates, to use country-specific values for monetizing climate damages, to represent SC-GHGs as distributions rather than as central values, and to conduct a temporal distributional analysis that shows how climate benefits are distributed among different generations. We also provide a suite of recommendations for appropriate discount rates for estimating SC-GHGs, and for the RIAs that incorporate them. Discount rates have a singular impact on SC-GHG estimates, given that benefits occur over several centuries. Hence, the choice of an intergenerational discount rate is a crucial normative judgment in the analysis. The discount rates proposed in our recommendations are based on consumer discount rates in the credit markets that are most relevant for RIA.

Acknowledgments. We are grateful to Tom Kniesner for thoughtful editorial guidance.

[11] See Fraas and Lutter (2013) and Krutilla *et al.* (2015) for Monte Carlo simulation applications in RIA.

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Cite this article: Fraas, A. G., J. D. Graham, K. M. Krutilla, R. Lutter, J. F. Shogren, L. Thunström, and W. K. Viscusi. 2023. "Seven Recommendations for Pricing Greenhouse Gas Emissions." *Journal of Benefit-Cost Analysis* 14: 191–204, doi:10.1017/bca.2023.31