ELECTRIC POWER RESEARCH INSTITUTE

Carbon Pricing and the Social Cost of Carbon

Discussion Paper

3002011391

Carbon Pricing and the Social Cost of Carbon

Discussion Paper

3002011391

Technical Update, December 2017

EPRI Project Manager

S Rose

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) PREPARED THIS REPORT.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

ACKNOWLEDGMENTS

The Electric Power Research Institute (EPRI) prepared this report.

Principal Investigator
S. Rose

This report describes research sponsored by EPRI. We wish to thank the High-Level Commission on Carbon Prices of the Carbon Pricing Leadership Coalition and World Bank Group who inspired the initial writing of this paper. An earlier version was prepared at the request of the Commission chaired by Professors Joseph Stiglitz and Lord Nicholas Stern. This paper was further inspired by the Harvard Electricity Policy Group (HEPG) and the Pricing Carbon Initiative (PCI) and their interest in the potential role of the social cost of carbon in carbon pricing. Individually, we wish to thank Stéphane Hallegatte, William Hogan, Tom Stokes, and Alden Meyer, as well as fellow panelists and participants in the HEPG and PCI events for their invaluable creative and critical comments.

This publication is a corporate document that should be cited in the literature in the following manner:

Rose, SK, 2017. *Carbon Pricing and the Social Cost of Carbon: Discussion Paper.* EPRI, Palo Alto, CA: 2017. 3002011391.

ABSTRACT

The social cost of carbon (SCC) is one of the values of carbon being considered in international and domestic discussions regarding the pricing of carbon dioxide emissions. The SCC is conceptually the marginal damage to society from emitting carbon dioxide (CO_2) and contributing to climate change. SCCs are regarded as an option for pricing carbon in that they represent a monetization of climate damage externalities from activities emitting CO_2 that could be internalized into decisions. However, there are essential conceptual and practical issues to consider. This study distinguishes different types of SCCs—baseline, optimal, and policy, and discusses issues regarding the state of the art for SCC estimation, global damage modeling, and optimal carbon pricing. The study also briefly discusses SCC (and carbon tax) application issues that can compromise CO_2 reduction benefit and net benefit estimates, as well as considers other options for developing a carbon tax.

Keywords
Social cost of carbon
Carbon pricing
Carbon tax
Climate change
Greenhouse gases
Climate damages

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1

CARBON PRICING AND THE SOCIAL COST OF CARBON

Introduction

The social cost of carbon (SCC) is one of the values of carbon being considered in carbon pricing discussions—internationally as policy-makers and stakeholders look to implement the Paris Agreement and realize its climate objective of limiting global average temperature to well below 2°C, and domestically in the United States as states and regions consider alternative policies for reducing greenhouse gas emissions. This report discusses a number of issues associated with the SCC and global damage modeling, and briefly reflects on application of the SCC and other carbon values.

The SCC is conceptually the marginal cost to society of emitting carbon dioxide (CO_2). Computationally, the SCC is the net present value of future global climate change impacts from one additional net global metric ton of CO_2 emitted to the atmosphere at a particular point in time (Figure 1). An SCC value is computed using two long-run scenarios – a reference scenario projecting a future global socioeconomic condition for centuries, and the resulting global greenhouse gas emissions, climate change, and net global damages from that climate change; and, a pulsed scenario projecting the incremental climate change and damages over time from the addition of a pulse of CO_2 in an individual year (e.g., 2020) to the reference scenario. An SCC in 2020, therefore, is the discounted value of the additional net damages from the marginal emissions increase in 2020 relative to the reference condition.

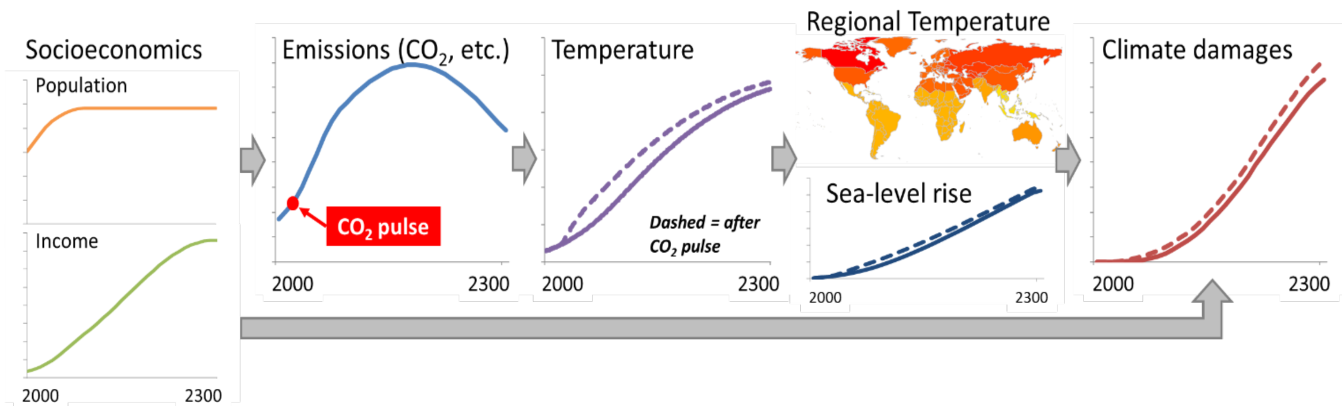

Figure 1
The causal chain of projections associated with computing a social cost of carbon estimate

Source: Rose et al. (2017a)

SCC values have appeared in the literature for decades, with a broad range of estimates varying by sign and multiple orders or magnitude (e.g., Tol, 2008). In general, these estimates are not all comparable with substantive differences in assumptions, methods, discounting, and application.

Not all SCCs are alike

Understandably, SCCs are regarded as an option for pricing carbon in that they represent a monetization of the climate damage externalities from activities emitting CO_2 that could be internalized into decisions by SCC pricing of emissions. However, not all SCCs are alike. It is useful to differentiate three types of SCC values: baseline, economically optimal, and policy. A baseline SCC is computed off of a reference scenario without future additional climate policies. An economically optimal SCC, on the other hand, is derived from the balancing the marginal costs and benefits (avoided damages) of reducing emissions over time to maximize societal welfare. This is also referred to as economic efficiency. Finally, a policy SCC is computed off of an emissions pathway constrained by a prescribed emissions reduction policy (associated with a long-run climate objective). See Figure 2 for illustrations of the three types of pathways.

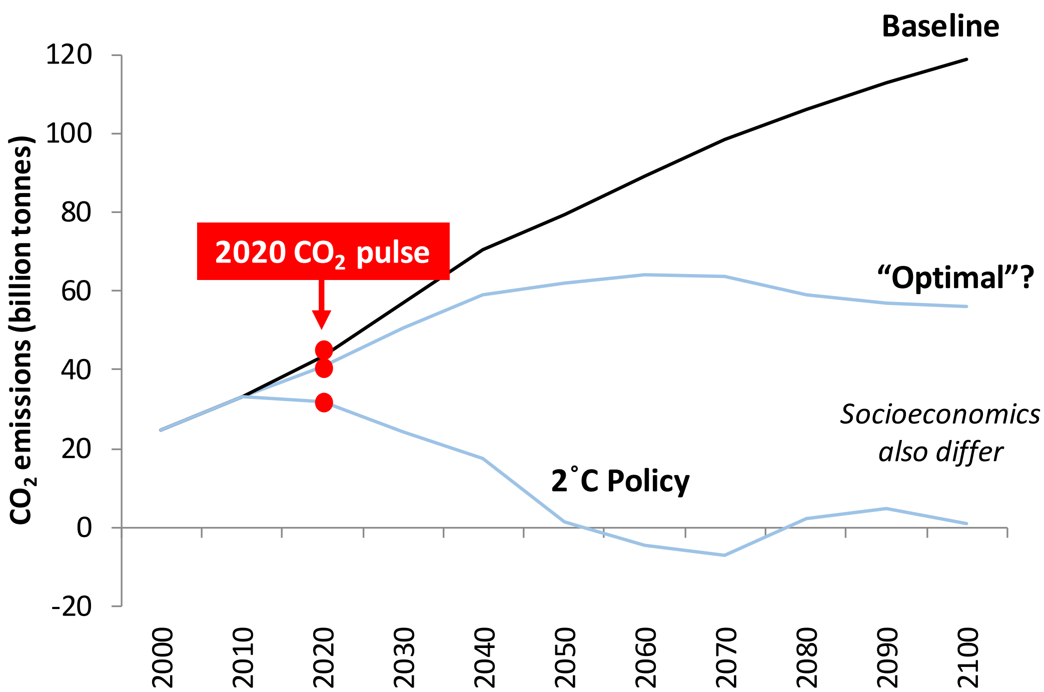

Figure 2
Illustrations of alternative global CO_2 emissions pathways

According to economic theory, a carbon price should be set equal to the optimal SCC over time, thereby maximizing social welfare. Some have suggested that the marginal benefit curve is flat and therefore the different SCCs will be similar; and, therefore, one need not worry about these distinctions and different calculations. That is not what we are finding. Using EPRI's MERGE integrated assessment model (Rose et al., 2017b; Blanford et al., 2014a), we ran illustrative baseline (no future additional climate policy), 2°C policy (limiting global average temperature to 2°C), and economically optimal scenarios (balancing marginal benefits and costs over time) using climate damage functions fitted to the SCC damage component deterministic assessment results from Rose et al. (2017a) and endogenous discounting. For each resulting emissions and climate pathway, we compute the SCC.

Table 1
Illustrative 2020 and 2100 SCC values for Figure 2 "Baseline" and "2°C Policy" pathways ($/t$CO_2$)

U-PAGE*	2020	2100	U-FUND*	2020	2100
Baseline	$21	$123	Baseline	$6	$64
2˚C Policy	$17	$79	2˚C Policy	$0	$6

** Modeling using the MERGE model with damage functions fitted to Rose et al. (2014, 2017a) SCC damage component assessment results for U.S. Government versions of the FUND and PAGE models and endogenous discounting (Rose,2017).*

From this lean set of illustrative scenarios, we learn a lot. Specifically, we find that the SCC varies across the pathway types, with differences growing over time (Table 1). How much the difference grows over time will depend on factors such as the representation of damages, climate system response, discounting, and socioeconomics. The key finding is that marginal benefits are dynamic and the value of the first ton of emissions reduced will not equal the value of the last, especially for large emissions reductions like those required for pursuing the temperature goal of the Paris Agreement. The key conclusion is that ignoring changes in marginal benefits as emissions are reduced is problematic and will likely result in an over-estimation of benefits. Figure 3 provides a simple static picture to illustrate these points. The marginal benefit (MB) of reducing emissions off the baseline pathway is higher than the MB off the other pathways. If we used the baseline MB to value emissions reductions E*, we would overestimate the total benefits.

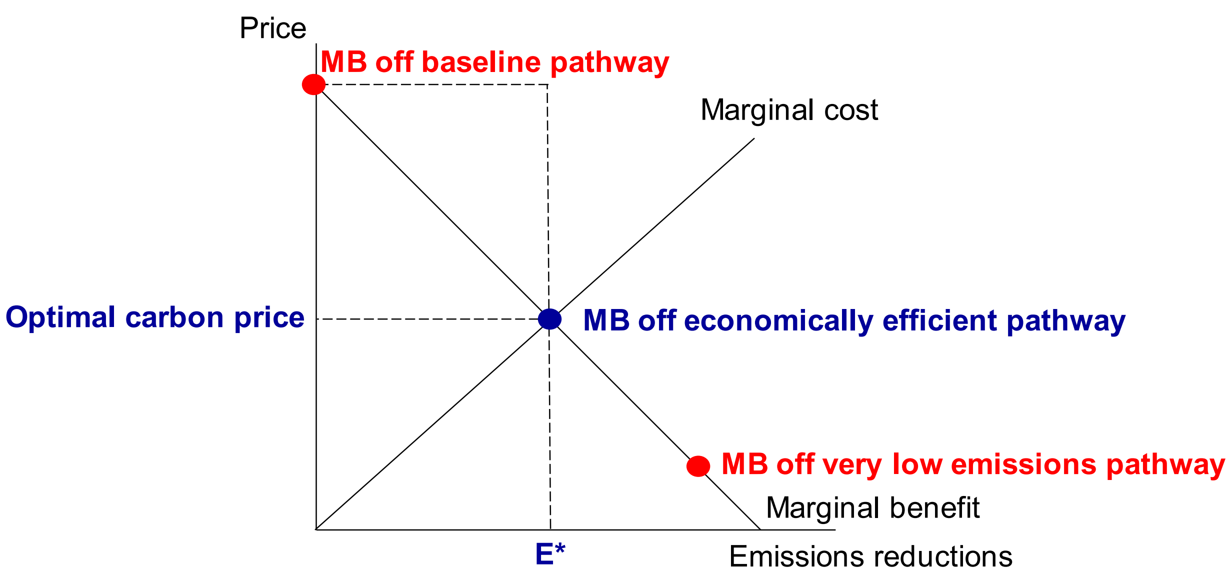

Figure 3
Static illustration of an economically optimal carbon tax

Next, we discuss two options for setting carbon prices—(1) U.S. Government SCCs, and (2) using aggregate damage modeling to derive optimal SCCs. We then take a step back and consider optimal emissions pathways generally and SCC application. Finally, we offer a few remarks on other carbon values, and end with concluding thoughts.

Are US Government global SCCs a viable option?

The short answer is, no. When entertaining SCC values, the US Government (USG) global SCC estimates are a logical option to consider.[1] The Obama Administration developed global SCC estimates for future emissions changes to 2050 for use in federal rulemakings. The methodology and initial estimates were developed in 2010, and revised estimates have been produced since based on the same methods with model updates and corrections (USG, 2010, 2013, 2015, and 2016). The methodology averages SCC results across three models (DICE, FUND, and PAGE) that each produce tens of thousands of SCC estimates running alternative assumptions regarding socioeconomic and emissions futures, as well as parameter values. The USG SCCs have been used in over 65 federal regulations since 2008, and use has propagated to other contexts as well—e.g., other U.S. federal actions, state policy, Canadian policy, and technology evaluation (see Rose and Bistline, 2016, for a summary).

Given the USG methodology, the resulting SCCs estimates are conceptually not optimal carbon prices. Specifically, they are not derived from balancing benefits and costs, with costs not considered at all in their derivation, marginal benefits unchanging with the level of emissions, and the values produced based on an amalgamation of futures (four baseline, one policy). The bottom line is that the USG SCCs were simply not designed to be a carbon tax. Furthermore, in addition to the conceptual mismatch, the underlying modeling has fundamental technical issues (discussed next).

Could aggregate global damage modeling be used?

The short answer here is also, no. The state of the art is problematic. A recent detailed component-by-component assessment and inter-model comparison of current modeling examines the raw modeling and behavior (undiscounted and disaggregated) of individual components of the various models used by the USG (Rose et al., 2014, 2017a). This research finds stark differences across models in the underlying structures and implementation. These differences result in significantly different outcomes—for projected climate change from the same emissions inputs, and projected damages from the same climate change and socioeconomic futures. Figures 4 and 5 provide examples. The issue is not that the results differ, but that these large differences in outcomes are driven by underlying differences in model features and implementation that are

[1] Note that, President Trump's March 28, 2017 Executive Order ("Promoting Energy Independence and Economic Growth") withdrew the Obama Administration's USG SCC estimates from federal regulatory use and provided alternative guidance for monetizing changes in greenhouse gases. The USG SCC estimates, however, continue to be relevant, with states, countries (e.g., Canada), other decision applications, and academics considering them for decision-making and as benchmarks (for examples, see Rose and Bistline, 2016). Recently, in an October 16, 2017 proposed rulemaking, the Trump Administration proposed SCC estimates based on domestic damages and an alternative set of discount rates. The underlying models and methodology used, however, are unchanged from the Obama Administration estimates (outside of assumptions for producing DICE domestic estimates and discounting).

not transparent, understood, or supported, and some of which result in artificial variation across models.

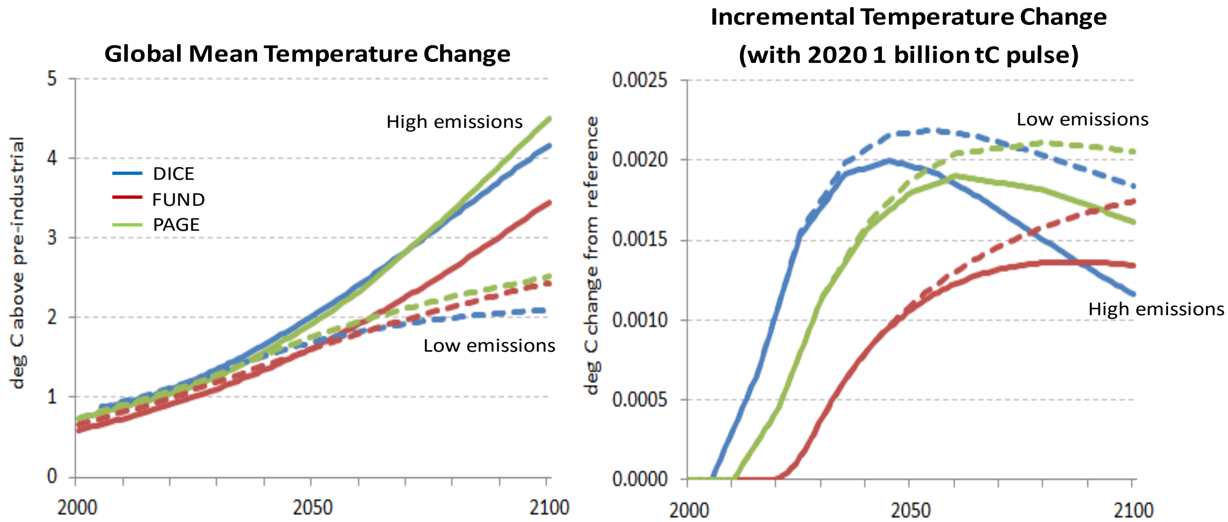

Figure 4
Projected global mean temperature change and incremental temperature change for a 2020 one billion tC pulse off of identical high and low emissions projections

Source: Rose et al. (2017a)

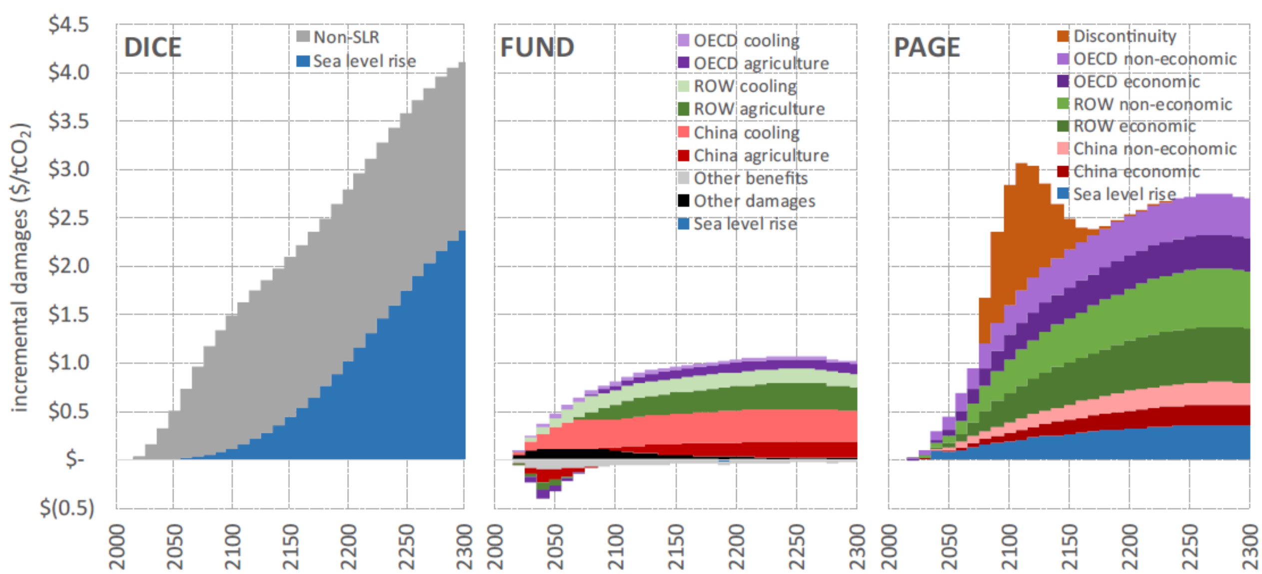

Figure 5
Projected incremental damages for an identical reference climate and socioeconomic future with a 2020 CO_2 pulse

Source: Rose et al. (2017a)

For instance, some models omit elements others include (e.g., categories of radiative forcing, climate system dynamics, parameter correlations), are inconsistency implemented, make strong parametric assumptions (e.g., lag in temperature response, damage response rate with temperature, regional damage scaling, discontinuity specification, adaptation responses to warming and sea level rise), and have tendencies across intermediate results towards higher (or lower) damage outcomes. Among other things, the identified differences suggest that the results from the various models may not be comparable due to structural and implementation differences that may not represent scientific uncertainty. Furthermore, current damage formulations are based on dated climate impacts literature (circa 1990/2000), with formulations in one model sometimes based on the formulations in the other models, which reduces the value of utilizing multiple models.

Going forward, for public and policy-maker confidence, it is essential to elucidate and evaluate the differences, and improve upon the modeling. Fortunately, there are clear opportunities for improvement—evaluating climate modeling, updating damage representations, improving transparency and justification, and improving consideration of uncertainty (structural and parametric). These issues are first order and need to be addressed. As is, it is impossible to assess the bias in current estimates as some researchers and others have already tried to do (e.g., Howard, 2014; Tol, 2009; IPCC, 2007).

Finding an optimal SCC

Damage modeling issues aside, finding an optimal SCC is a challenge because identifying an optimal emissions path is far from straightforward. With uncertainties throughout the causal chain from socioeconomics through to damages, a different "optimal" emissions (and temperature) pathway coincides with each plausible set of assumptions. Figure 6, for instance, presents "optimal" emissions pathways for different reasonable alternative combinations of assumptions regarding socioeconomics, climate dynamics, damages, and emissions abatement technology. A higher optimal emissions pathway is consistent with a less responsive climate system, the absence of key mitigation technologies, faster economic growth, higher energy intensity of growth, or lower expected damages. A low emissions pathway is consistent with a more responsive climate system, the availability of key mitigation technologies, slower economic growth, lower energy intensity of growth, or higher expected damages. Overall, the figure highlights the challenge of simply defining the uncertainty space, i.e., possible states of the world. This is a requisite first step, after which one would need to consider assigning probabilities for each uncertainty, stochastic modeling to internalize the uncertainty in decision-making, and ultimately identifying a single optimal pathway.

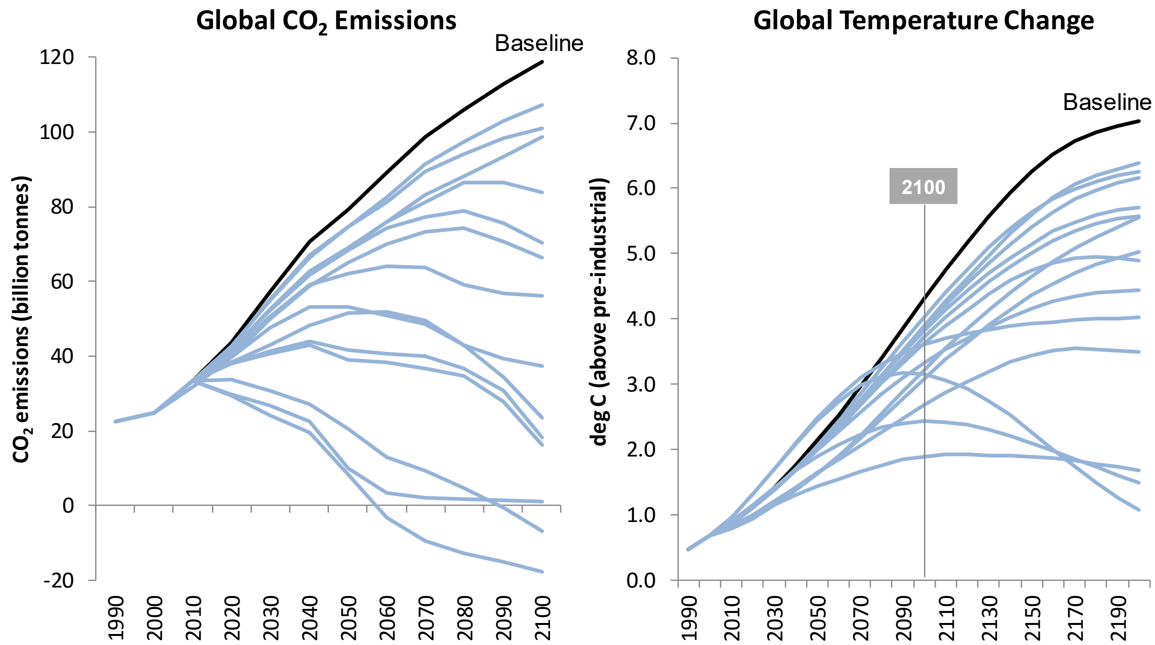

Figure 6
Optimal emissions and temperature pathways for alternative sets of assumptions

Source: Rose (2017)

Carbon price application

Most SCC literature and discussion focuses on damage estimation. However, there are also important SCC and, more generally, carbon tax, application issues that are overlooked. These issues impact the reliability of CO_2 reduction benefit and net benefit calculations, and potentially the insights and conclusions drawn. See Rose and Bistline (2016) for in-depth discussion. For instance, there are frequently inconsistencies across benefit and cost calculations in reference assumptions, treatment of uncertainty, and even the types of values compared in cost-benefit analyses. In addition, global CO_2 effects are typically not estimated, with policies ignoring potential CO_2 changes beyond the regulated segment. These CO_2 changes, if they exist, represent emissions leakage and affect the CO_2 benefits of policies (e.g., x% leakage = x% lower CO_2 benefits). For instance, Bistline and Rose (2017) evaluated potential leakage in the US energy system with subnational SCC pricing of power sector CO_2 emissions, and found CO_2 leakage affecting net emissions reductions in all the cases evaluated, with leakage sometimes substantial (e.g., 80%).

Also observed are inconsistencies in SCC use across policies, which creates distortions that result in inefficient resource allocation by assigning different values to different sources of CO_2. Finally, policy coordination is required to avoid pricing of the CO_2 externality more than once. In the last year, there are examples in the U.S. of the same carbon being priced in coal extraction, as well as at the time of coal combustion by state utility regulators, and again by federal Clean Air Act policy. Similarly, some states have low-carbon generation subsidies, in addition to regional greenhouse gas emissions caps, not to mention potential national emissions policies.

With jurisdictions acting independently, this is difficult to avoid, but economically inefficient as multiple pricing of CO_2 will result in the inefficient allocation of resources.

Other carbon values

SCCs are not the only carbon pricing options. There are for instance, policy marginal costs of abatement derived from quantity mechanisms that constrain emissions (directly, or indirectly via atmospheric concentration or temperature objectives). Emissions abatement research has produced a rich literature with marginal cost carbon prices associated with various policy targets and assumptions. In this context, monetized damages are not required. However, perceptions of risk are still the basis for targets. This literature has shown that abatement costs are increasing and non-linear (Rose et al., 2017b; Clarke et al., 2014); and, in particular, the marginal cost of incrementally lowering temperature constraints could rise quickly and be substantial (e.g., Blanford et al., 2014b). This literature has also begun to explore second best policies that are more consistent with the world's current and likely future policy path, finding substantial cost increases with less optimistic futures regarding abatement participation and coverage and the availability of technology (Riahi et al., 2015; Clarke et al., 2014). This research is evolving and still relatively abstract and aggregate with respect to actual institutions and policy design. Additional factors, such as investment risks and incentive mechanisms, are generally not represented but will also affect costs (e.g., Rose et al., in press). While damages are currently difficult to quantify, the potential for high abatement costs implies that there is value in considering what one needs to believe to justify the cost.

Conclusion

It is important to recognize that there are different types of SCCs—baseline, optimal, and policy. Theoretically, a carbon tax should be based on an optimal emissions pathway that balances marginal benefits and costs. However, an optimal pathway and implied carbon tax path are elusive. Conceptually, the USG SCCs are not appropriate. Practically, the state of the art for global damage modeling is not up to the task; and, more generally, an optimal emissions pathway is challenging to identify. SCC (and carbon tax) application issues are also important in that they can affect estimates of CO_2 reduction benefits and net benefits. Finally, there are other options for developing a carbon tax; in particular, policy marginal costs. Nonetheless, it will be important to consider non-linearity in mitigation costs, second-best policy worlds, and other cost factors, as well as perceptions of climate risk that could justify the costs.

2
REFERENCES

Bistline and Rose, 2017. Social Cost of Carbon Pricing of Power Sector CO_2: Accounting for Leakage and Other Social Implications from Subnational Policies. *Environmental Research Letters*, in press.

Blanford, G, J Merrick, R Richels, S Rose, 2014a. Trade-offs between mitigation costs and temperature change. *Climatic Change* 123(3-4): 527-541.

Blanford, G.J., R. Mendelsohn, S.K. Rose, and R. Richels, 2014b. *The Price of a Degree: Marginal Mitigation Costs of Achieving Long-Term Temperature Targets*. EPRI, Palo Alto, CA: 3002003937.

Clarke L et al., 2014. Assessing Transformation Pathways. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O et al (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Howard, P, 2014. *Omitted damages: What's missing from the social cost of carbon.* The Cost of Carbon Project of the Environmental Defense Fund, the Institute for Policy Integrity, and the Natural Resources Defense Council. March. Available at: http://costofcarbon.org/reports (last accessed December 19, 2017).

IPCC, 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ML Parry, OF Canziani, JP Palutikof, PJ van der Linden and CE Hanson (eds.). Cambridge, UK: Cambridge University Press.

Riahi, K et al., 2015. Locked into Copenhagen pledges — Implications of short-term emission targets for the cost and feasibility of long-term climate goals. *Tech Forecasting and Social Change* 90 (Part A): 8-23.

Rose, S.K., 2017. *Managing Climate Damages: Exploring Trade-Offs*. Discussion Paper. EPRI, Palo Alto, CA: 2017. 3002009659.

Rose, S.K., R. Beach, K. Calvin, B. McCarl, J. Petrusa, B. Sohngen, R. Youngman, A. Diamant, F. de la Chesnaye, J. Edmonds, R. Rosenzweig, M. Wise, in press. *Market Realities for Global Mitigation Supplies: Accounting for Risks and Incentives*. Report #1025510.

Rose, S.K. and J. Bistline, 2016. *Applying the Social Cost of Carbon: Technical Considerations.* EPRI, Palo Alto, CA. Report #3002004659, http://epri.co/3002004659.

Rose, S.K., D. Diaz, G. Blanford, 2017a. Understanding the Social Cost of Carbon: A Model Diagnostic and Inter-Comparison Study, *Climate Change Economics*, Vol. 8, No. 2.

Rose, S.K., R. Richels, G. Blanford, T. Rutherford, 2017b. The Paris Agreement and Next Steps in Limiting Global Warming. *Climatic Change* 142(1), 255-270. DOI 10.1007/s10584-017-1935-y.

Rose, S.K. D. Turner, G. Blanford, J. Bistline, F. de la Chesnaye, and T. Wilson, 2014. *Understanding the Social Cost of Carbon: A Technical Assessment*. EPRI, Palo Alto, CA. Report #3002004657, http://epri.co/3002004657. (Journal version in review)

Tol, R.S.J., 2008. The social cost of carbon: trends, outliers and catastrophes. *Economics: The Open-Access, Open-Assessment E-Journal*, No. 2008-25, August 12, 2008. Available at: http://www.economics-ejournal.org/economics/journalarticles/2008-25.

Tol, R, 2009. The economic effects of climate change. *Journal of Economic Perspectives*, 23, 29–51.

USG, 2010. Appendix 15A. *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, Interagency Working Group on Social Cost of Carbon, March.

USG, 2013. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, Interagency Working Group on Social Cost of Carbon, May.

USG, 2015. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, Interagency Working Group on Social Cost of Carbon, July.

USG, 2016. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, Interagency Working Group on Social Cost of Greenhouse Gases, August.

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI members represent 90% of the electric utility revenue in the United States with international participation in 35 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together…Shaping the Future of Electricity

3002011391

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com