ANNUAL REVIEWS

Annual Review of Resource Economics

Environmental Benefit-Cost Analysis: A Comparative Analysis Between the United States and the United Kingdom

Joseph E. Aldy,[1] Giles Atkinson,[2] and Matthew J. Kotchen[3]

[1]Harvard Kennedy School, Harvard University, Cambridge, Massachusetts 02138, USA

[2]Department of Geography and Environment and Grantham Research Institute on Climate Change and Environment, London School of Economics and Political Science, London WC2A 2AE, United Kingdom; email: g.atkinson@lse.ac.uk

[3]Yale School of the Environment, Yale University, New Haven, Connecticut 06511, USA

Annu. Rev. Resour. Econ. 2021. 13:267–88

First published as a Review in Advance on July 6, 2021

The *Annual Review of Resource Economics* is online at resource.annualreviews.org

https://doi.org/10.1146/annurev-resource-040821-045913

JEL codes: H43, Q51, Q54, Q58

Keywords

benefit-cost analysis, social cost of carbon, social discount rate, value of statistical life, regulatory impact analysis

Abstract

The United States and United Kingdom have long-standing traditions in the use of environmental benefit-cost analysis (E-BCA). While there are similarities between how E-BCA is utilized, there are significant differences too, many of which mirror ongoing debates and recent developments in the literature on environmental and natural resource economics. We review the use of E-BCA in both countries across three themes: (*a*) the role of long-term discounting, (*b*) the estimation and use of carbon valuation, and (*c*) the estimation and use of the value of a statistical life. In each case, we discuss how academic developments are (and are not) translated into practical use and draw comparative lessons. We find that, in some cases, practical differences in E-BCA can be overstated, although in others these seem more substantive. Advances in the academic frontier also raise the question of when and how to update practical E-BCA, with very different answers across our themes.

1. INTRODUCTION

The United States and United Kingdom are two countries with long-standing traditions in the use of benefit-cost analysis (BCA) for the appraisal of public policies. One area where BCA has grown increasingly important in both countries is applications to environmental policies or, more broadly, policies with environmental impacts, which we henceforth refer to as environmental BCA (or E-BCA).[1] There are striking similarities between the two countries in how E-BCA is utilized in the policy process, including official guidelines that establish how it is to be conducted and employed at the national level. There are, however, significant differences too, many of which mirror ongoing debates and recent developments in the field of environmental and natural resource economics. In some instances, the two countries have differed in how academic developments have translated into practical use, and some of these differences can be explained by the political and institutional context in which E-BCA is applied in each country.

In this article, we review the use of E-BCA in the United States and United Kingdom with particular reference to selected themes. Critically important questions in the application of E-BCA to contemporary environmental challenges include: How should benefits and costs that occur at different points in time—especially over long time horizons—be compared? How should the geographic and political boundaries of an analysis be drawn when environmental problems are increasingly of a transboundary nature? And how should the largest category of nonmarket values—i.e., those that affect human health and safety—be reflected in an E-BCA, where different assumptions often play a decisive role?

Accordingly, our review focuses on (*a*) the role of discounting for long-term impacts such as those associated with climate change, (*b*) estimation and use of the social cost of carbon (SCC) and other carbon pricing approaches for evaluating domestic policy in the context of global climate change, and (*c*) different approaches for estimating and using the value of a statistical life. When considering each of these areas, we discuss in particular how academic developments are (and are not) translated into practical use at the national level, drawing lessons based on comparisons between the United States and United Kingdom.

We begin with a broad overview of what distinguishes E-BCA from BCA more generally. We then organize the review into different sections that consider discounting, pricing carbon emissions, and valuing mortality risk reduction. When discussing each of these topics, we reflect on broader questions about why in some cases academic developments have, and have not, translated into updated guidance for E-BCA in the United States and United Kingdom. Finally, we consider commonalities across sections in drawing conclusions based on our comparison of the two countries.

2. ENVIRONMENTAL BENEFIT-COST ANALYSIS

At the broadest level, any BCA involves the same principles. The aim is to quantify and compare benefits and costs of moving from one state of the world to another in ways that conform with basic principles of welfare economics (Just et al. 1981, Boardman et al. 2018) What is best practice in appraising environmental impacts as part of an E-BCA carries over to BCAs more generally. There are, however, issues that tend to arise in E-BCAs that lead to topics of particular interest within the research community and that require judgement about how they are resolved in practice as part of official policy and program evaluations. Interestingly, many of the recent developments

[1] See, e.g., Pearce (1998) and Atkinson et al. (2018b) for reviews of the use of E-BCA in the United Kingdom and Hahn & Dudley (2007) and Hahn & Tetlock (2008) for the United States.

in how economists recommend that BCAs be carried out have their origins in understanding how to better account for environmental impacts within the ambit of a standard BCA (Pearce et al. 2006, Atkinson et al. 2018a).

A basic starting point for all BCAs is a determination of whose benefits and costs should count. The determination must be made over space and time. Typically, the political jurisdiction of the proposal being appraised defines the relevant population. For example, the residents of a country are usually the relevant population for policies that apply at the national level. As discussed below, however, cases where impacts spill over to other jurisdictions can be highly relevant to environmental applications and raise important questions for E-BCA. All BCAs must also specify the planning horizon over which benefits and costs count, and this issue can be particularly important and consequential when it comes to long-term, intergenerational concerns like climate change.

Discounting is a related feature of BCAs that can significantly affect results. When costs and benefits occur at different points in time, discounting provides the weights to facilitate intertemporal comparisons by converting all future costs and benefits into present values. The cost-benefit criterion is then a question of whether the present value of net benefits is positive. With respect to impacts that occur far into the future, important questions affecting E-BCA are how to discount, in addition to what rates should be employed.

A further challenge in conducting E-BCAs, and perhaps the one that most distinguishes them from BCAs more generally, is that many environmental benefits and costs do not immediately translate into monetary values. The most common way for economists to measure an individual's or a household's value is willingness to pay (WTP). But there are many things that people value, such as improved environmental quality and lower mortality risk, for which they pay nothing, at least not directly. In order to account for these values, BCA often requires the use of nonmarket valuation techniques, where the aim is to infer WTP (or sometimes willingness to accept compensation) for things that are not directly traded in markets and for which there are no immediate prices.

Broadly speaking, economists carry out nonmarket valuation using revealed or stated preference techniques (for an overview, see Champ et al. 2017, Atkinson et al. 2018a). Consider the applications of both approaches to estimate WTP to reduce premature mortality risk. Revealed preference methods estimate the income an individual gives up (requires) for a small decrease (increase) in one's own mortality risk exposure in market transactions, such as employment decisions, as well as vehicle and home purchases. Since the 1970s, economists have estimated hedonic wage models to estimate the compensating differential for occupational fatality risk, which represents the most common revealed preference value of statistical life (VSL) approach (Viscusi & Aldy 2003, Viscusi 2018). The appeal of these revealed preference studies lies in the estimation of WTP for small changes of mortality risk, comparable in magnitude to the risk reductions typical of individual regulations, that reflects individuals' decisions in markets.[2]

In stated preference approaches, hypothetical risk-income trade-offs through survey instruments enable the elicitation of WTP (Chilton et al. 1999, 2004; Krupnick 2007). These survey approaches create contingent markets that can more closely relate to the policy context. For example, Alberini et al. (2004) describe hypothetical risk interventions that deliver latent health

[2]The quality of labor market and occupational fatality risk data as well as issues in the design and execution of rigorous empirical strategies pose challenges that have been identified in this literature (Black & Kniesner 2003; Viscusi & Aldy 2003; Ashenfelter & Greenstone 2004; Viscusi 2004, 2015). An array of more recent publications has attempted to address these shortcomings (e.g., Kniesner et al. 2012, Aldy 2019, Lee & Taylor 2019, Lavetti 2020).

Table 1 Official benefit-cost analysis of two major climate policies in the United States and United Kingdom (in billions of 2019 USD)

	US Clean Power Plan, benefits and costs in 2030		UK Climate Change Act, annualized benefits and costs 2008–2050
	3% discount rate	7% discount rate	3.5% discount rate
Climate benefits	23	23	31–72
Air quality co-benefits	16–39	15–36	2
Compliance costs	9.6	9.6	23–29
Net benefits	29–52	28–49	4–51

Data from US EPA (2015) and DECC (2009). Although we report the US estimates for the year 2030, the US EPA analysis also reports estimates for 2020 and 2025. The UK estimates are annualized values of policy-induced changes over the whole period being appraised, 2008–2050. We convert original estimates to 2019 USD.

benefits using contingent valuation.[3] The resulting WTP for these risk reductions may better map to the latent health benefits associated with reduced particulate matter exposure than the WTP to reduce current period mortality risk estimated in hedonic wage models. The challenge in stated preference approaches, however, lies in the potential for survey participants to state their WTP in a manner that may not be consistent with their true preferences over income and risk (for alternative perspectives, see Carson 2012, Hausman 2012).

The BCA practitioner thus has an array of approaches within the nonmarket valuation toolkit, and often at issue is the question of which approach to utilize in which context. The growing empirical literature in several areas has been distilled to produce reference values as a result of meta-analysis or some other approach (e.g., OECD 2012). Moreover, methods have been developed with varying degrees of sophistication to promote transfer of estimates from one study to another, through a process known as benefits transfer (see, e.g., Johnston et al. 2015).

Developments in the academic literature have practical significance for how E-BCAs are undertaken in practice. **Table 1** illustrates two examples (in 2019 US dollars).[4] In the first, the US Environmental Protection Agency (US EPA 2015) provides a BCA of the US Clean Power Plan, which sought to regulate the US electricity generation sector to reduce carbon dioxide (CO_2) emissions 32% below 2005 levels by 2030.[5] In the second example, the UK Department of Energy and Climate Change (DECC 2009) provides a BCA of the UK Climate Change Act 2008, which set a statutory target to reduce greenhouse gas emissions 80% below 1990 levels by 2050. The table reports net benefits of each appraisal, along with component benefits and costs. The UK numbers are annualized values over the whole period being appraised, whereas the US numbers are for a single representative year.

Key elements of both analyses include the following: The benefits and costs occur over long periods of time, and this necessitates discounting. Reducing emissions provides benefits in the form of avoided climate damages, and estimating these benefits requires a mechanism to value the SCC or to price carbon emissions through some other means. Finally, there are air quality co-benefits because of reductions in other pollutants that have adverse effects on human health,

[3]The article by Mitchell & Carson (1989) remains the seminal text on the contingent valuation method. Another prominent stated preference approach is discrete choice experiments, especially in contexts where policy changes have multiple attributes that command distinct valuations (Louviere et al. 2000).

[4]Throughout this review we have converted all monetary values to 2019 base year currency using each country's official series of GDP deflators. For the reader's reference, the 2019 dollar-pound exchange rate was 1.28.

[5]The Clean Power Plan was ultimately replaced by the Affordable Clean Energy Rule in 2019.

and the value of these benefits hinges largely on the VSL as a measure of lower mortality risks. Each of these elements represents a topic that we now consider in turn.

3. THE SOCIAL DISCOUNT RATE

Few areas of BCA have generated as much heated scholarly debate over the past two decades as that of the correct social discount rate (SDR). Basic questions relate to which discount rate should be used and how it should be applied. Ongoing debates also wrestle with questions about whether BCA is up to the task of informing public policy when benefits and costs are intergenerational.[6] We find that the US and UK approaches differ conceptually, having drawn on different streams of research, yet the effect in practice is likely less than one might expect.

3.1. The US and UK Approaches

At the most basic level, discounting assigns a lower weight to benefits and costs that occur further into the future. To illustrate, let w_t be the weight attached to a gain or loss in any future year t such that $w_t = 1/(1+r)^t$. The magnitude of this weight—the discount factor—is determined by the SDR, r, as well as the number of t years into the future. Specifically, r measures the percentage rate of decline in the discount factor. In conventional BCA, r is typically a rate that is appropriate for discounting benefits and costs for risk-free projects and regulations. It is based, in turn, on returns to relatively risk-free investments or on judgements about how consumption is distributed over time.

In most cases, the choice of r is also constant; that is, the SDR takes the same value regardless of when the benefits or costs occur. This is the approach employed by the US government for federal BCAs, for which official guidance recommends two different rates, 3% and 7%, as a range to examine sensitivity of the results (OMB 1992, 2003). The UK approach differs for discounting the distant future (Lowe 2008). It is similar to the United States in that a constant SDR is used initially for the first 30 years, though it is set at 3.5%. The crucial difference is that the UK SDR declines over time at discrete intervals. For example, a rate of 2.5% is used for years 76 through 125, and ultimately the rate reaches a lower bound of 1% for 300 years and beyond. For sensitivity analysis the United Kingdom also has a schedule of lower discount rates, starting at 3.0%.[7]

The United Kingdom was an early adopter of the idea that the SDR should be declining. The basic argument in favor of this approach was driven by (then) recent academic developments relating to uncertainty about future discount rates, especially those by Weitzman (1998, 2001) (for discussions, see Arrow et al. 2014, Groom & Hepburn 2017). This early research showed that if there is a persistent element to uncertainty over the SDR, there is an effective, certainty-equivalent SDR that declines over time that can be used in BCA. A number of important contributions have subsequently provided clarity on the theory and practice of a declining SDR (see, e.g., Gollier 2012). The focus of much of this work has been on not only the implications of uncertainty about future consumption but also the ways in which social decision makers regard that risk. Although the US government has acknowledged the promise of such approaches, it has not made it into official guidance, with one argument being that the uncertainty can be captured instead by using a somewhat lower SDR for benefits and costs occurring in the far distant future (CEA 2017).

[6] See, e.g., Lind et al. (1982) and Markandya & Pearce (1991) for early discussions on the question.
[7] Specifically, these full SDRs are as follows (with the sensitivity rate in parentheses): 0–30 years: 3.5% (3.0%); 31–75 years: 3% (2.57%); 76–125 years: 2.5% (2.14%); 126–200 years: 2% (1.71%); 201–300 years: 1.5% (1.29%); 301+ years: 1% (0.86%).

A further difference between the US and UK approaches to discounting relates to the process whereby the rates are determined. Some of this difference can be viewed through the Ramsey formula, which equates the opportunity cost of capital in period t, denoted r_t, with the social rate of time preference, *SRTP* (for a discussion, see Atkinson et al. 2018a). Specifically, the rule is $r_t = \rho + \eta \cdot g_t$, where the right-hand side is the *SRTP* that consists of two terms. The first, ρ, is a time preference parameter that captures a combination of the pure rate of time preference and catastrophic or systemic risks. The second is the product of the elasticity of the marginal utility of consumption, η, and the real growth rate of consumption, g_t. In theory and given a number of assumptions, the two ways of viewing the SDR would be equal over time, but there is little reason to expect that this equality will hold in practice.

At a general level, one might thus characterize the US approach as based on the left-hand side of the Ramsey formula, whereas the UK approach is based on the right-hand side. Specifically, the US SDR is set with reference to observations about actual interest rates and returns on investments. For example, the 3% rate is a consumption-based discount rate, in turn, based on historical evidence on post-tax returns on saving (specifically, returns on government bonds or long-term government debt), and the 7% rate is most obviously an opportunity cost rate based on evidence on the pretax rate of return on capital private investments. By contrast, in the United Kingdom, the initial level of its SDR at 3.5% is set based on an empirical review of the parameter estimates for ρ, η, and g prepared for HM Treasury, initially by OXERA (2002) and later by Freeman et al. (2018). These parameters were then used to build up and estimate the SDR rather than inferring one based on observed market rates.

3.2. Practical Differences and Updating

How much of a difference do the contrasting approaches between the United States and United Kingdom make in practice? The answer, of course, depends on the specific policy or project being evaluated. We nevertheless provide a graphical comparison in **Figure 1** of the implied discount factors over time. **Figure 1*a*** compares the implied discount factor over 76 years for the US 3%

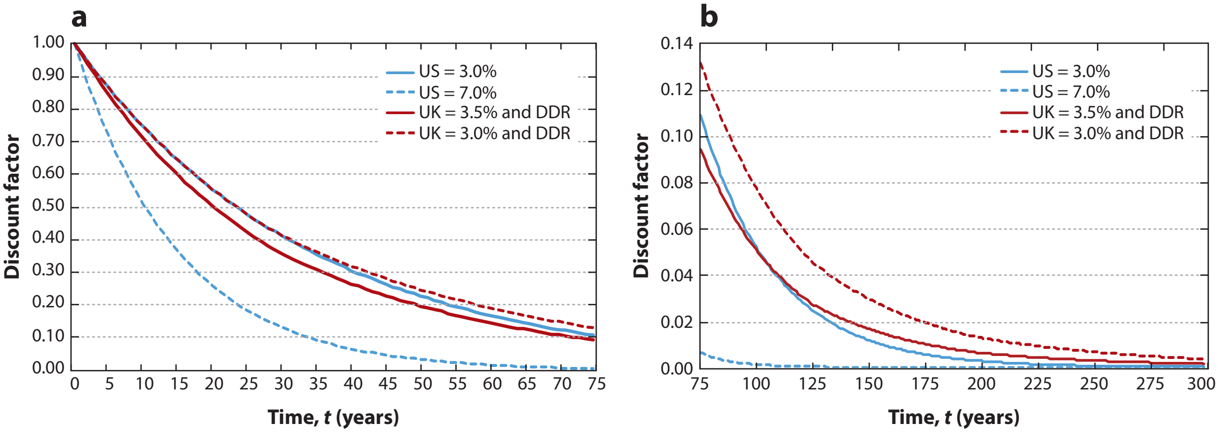

Figure 1

The implied discount factors under different official scenarios in the United States (US) and the United Kingdom (UK). (*a*) The trends for each year out to $t = 75$. (*b*) The implied discount factors from $t = 75$ out to $t = 300$. In the case of the UK, the discount factor is estimated from a declining discount rate (DDR). Authors' calculations are based on data on social discount rates from OMB (2003) and HM Treas. (2018).

and 7% scenarios and the UK 3.5% and 3.0% scenarios along with the associated declining rate schedules. The figure makes clear that the practical differences between the US 3% scenario and the UK scenarios is relatively small, as would be expected. In **Figure 1*b***, we focus on these US and UK scenarios for $t = 75$ out to $t = 300$. The figure shows that discount factors for the US 3% scenario are higher for the US than the UK 3.5% scenario until $t = 105$, although it is worth emphasizing that the discount factors are exceedingly small in both regimes hundreds of years into the future. That said, it is worth noting that the UK approach when introduced in 2003 was a substantial change from its previous official rate of a constant 6%.

The preceding discussion shows how both the United States and United Kingdom rely on empirical evidence for establishing official SDRs rather than on moral arguments.[8] This raises the question, then, of how SDRs are updated in the face of new empirical evidence, be these incremental changes, or, as in the UK case, a more substantial revision. Groom & Hepburn (2017) examine possible reasons for the United Kingdom's shift to a declining discount rate in 2003. They identify the importance of new ideas from influential individuals in the research community, although political and policy processes remain important as well. In the United States, which remains focused on using a constant SDR, the Council of Economic Advisers (CEA 2017) discusses the implications of secular declines in the rates of return on government bonds and investments that underlie the official guidance on discounting from the Office of Management and Budget (OMB 2003). Nonetheless, the official SDRs of 3% and 7% remain preserved, at least for the time being, perhaps suggesting the importance of opportunity windows to enabling change.[9] This is, however, evolving, with the White House (2021) reaffirming an explicit recognition of future generations in the context of regulatory assessment. More recently, the United Kingdom has also kept its discounting procedures in its most recent updated guidance (HM Treas. 2018). This includes the retention of the term structure for its declining SDR despite more recent arguments in theory and in empirical practice that call for potential revisions (e.g., Gollier 2012, Gollier & Hammitt 2014).

4. CARBON PRICING

To quantify the value of changing the flow of CO_2 emissions, the SCC has emerged as a key concept in BCAs. It reflects the marginal external costs of emissions—that is, the monetized damage caused by each additional unit of CO_2 emitted into the atmosphere. In this section, we discuss how the SCC has been used for federal BCA in the United States, along with some of the controversy it has generated. Additionally, we compare the US approach to an alternative notion of a regulatory shadow value that has been estimated and employed in the United Kingdom. A theme of our discussion is that climate change and carbon pricing raise new and challenging questions about the role of BCA in the context of global environmental problems.

4.1. The US Approach to the Social Cost of Carbon

In an effort to coordinate a uniform approach to valuing climate damages, the US government convened an interagency working group to estimate the SCC for use in federal BCAs. The initial work culminated in a 2010 report with a set of estimates covering a range of different assumptions, including the SDR (IAWGSCC 2010, Greenstone et al. 2013). The methods employed, which

[8]See Stern (2006) for an alternative, more prescriptive approach. Both the United States and United Kingdom nevertheless recognize moral concerns, especially in their guidance on sensitivity analysis (Lowe 2008, HM Treas. 2018, US EPA 2020).

[9]For a comprehensive reflection on theories of the policy process, see Weible & Sabatier (2018).

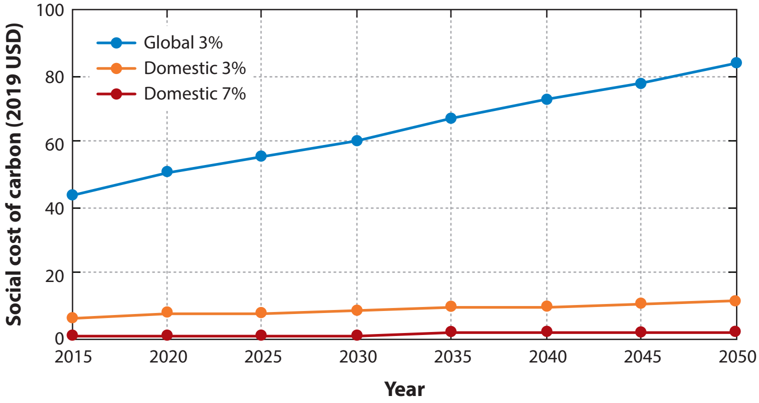

Figure 2

The social cost of carbon estimates by the US Interagency Working Group for the global 3% scenario (IAWGSCC 2016), along with the alternative assumptions employed by the Trump administration to narrow consideration to the domestic 3% and 7% scenarios (US EPA 2019).

rely on a synthesis of three integrated assessment models (IAMs), derive the SCC as an estimate of the global shadow value (cost) of emissions based on an assumed business-as-usual emissions pathway. The US government issued periodic technical updates reflecting more recent versions of the IAMs (IAWGSCC 2013, 2015, 2016), and regulatory agencies used these updated estimates in numerous federal BCAs prior to changes implemented by the Trump administration (see below). These estimates of the SCC nevertheless continue to provide the standard estimates employed in the academic, peer-reviewed literature and for evaluating state-level policies in the United States (Paul et al. 2017, Grab et al. 2019).

Figure 2 shows these values in 2019 USD. The SCC increases over time, reflecting greater damages because of a growing stock of greenhouse gases in the atmosphere and a growing economy upon which damages are inflicted. We present results focused on the central value of a 3% SDR, which was the Interagency Working Group on Social Cost of Carbon's (IAWGSCC's) recommended scenario for primary analysis. Note that despite the US approach for using 3% and 7% for BCAs more generally, use of the 3% scenario for estimating the SCC is justified based on the long-term nature of climate damages and uncertainty (IAWGSCC 2010, CEA 2017).

These estimates and their use have generated controversy. Some claim that IAMs are not well suited to provide defensible estimates given the significant uncertainties (Pindyck 2013, 2017). Others defend their use based on the need for quantitative economic evaluation and the potential for improvement over time (Metcalf & Stock 2017). A US National Academies of Sciences, Engineering, and Medicine (Natl. Acad. Sci. Eng. Med. 2017) panel was convened to review the existing approach for estimating the SCC and outlined a set of recommendations for its continued improvement.

Legal concerns and conceptual questions have also been raised. The SCC estimates represent the global damages that arise from emitting a tonne of CO_2, yet some argue that the United States should only account for the domestic damages, and use of the global SCC represents a dramatic shift in the scope of benefits estimation (Dudley & Mannix 2014, Rowell 2015, Darmstadter 2016, Fraas et al. 2016, Gayer & Viscusi 2016). Others argue instead that climate change is a unique global challenge that requires inclusion of the full, global externality in order to make real progress to address the problem (Greenstone et al. 2013, Pizer et al. 2014, Revesz et al. 2017). Others show how accounting for the global SCC can be individually rational when taking account of the potential for altruistic preferences, reciprocity, and the repeated-game nature of international climate agreements (Kopp & Mignone 2013, Kotchen 2018).

In a dramatic shift, one of the Trump administration's first actions in 2017, through Executive Order 13783, was to disband the IAWGSCC and withdraw the existing estimates from use in federal BCAs. As an interim measure, the Trump administration developed its own estimates of the SCC as part of its repeal of the Clean Power Plan and replacement with the Affordable Clean Energy rule (US EPA 2019). While much of the general approach remained the same, two methodological changes were made that have significant implications. The first was narrowing the consideration to only the domestic damages from global damages. The second was a returned focus to the two discount rate scenarios of 3% and 7%.

Figure 2 shows the impact of these alternative assumptions on estimates of the SCC. Counting only the domestic damages reduces the cost of emissions substantially, even keeping the discount rate at 3%. In 2020, the cost is reduced from $51 to less than $8, and in 2050, the reduction is from $84 to $12. Increasing the discount rate to 7% reduces the costs even further, rendering costs at $1 per tonne in 2020 and only $2 per tonne in 2050.

Referring back to **Table 1**, we can also see how these changes impact the analysis of an actual climate policy in the United States. The original BCA of the Clean Power Plan estimated climate benefits in the year 2030 at $23 billion. Applying instead the Trump administration's revised estimates of the SCC reduces these benefits substantially. Focusing on domestic damages alone, while keeping the 3% SDR, reduces the climate benefits from $23 billion to $3 billion. Increasing the SDR to 7% reduces the climate benefits even further, to only $400 million, effectively making them zero in the context of the other Clean Power Plan benefits and costs. These comparisons illustrate how the alternative assumptions about the SCC for BCAs can have significant effects. Although the health cobenefits are large enough in the example of the Clean Power Plan that the change in SCC does not flip the sign of net benefits, the same may not be true for policies where the avoided climate damages comprise a greater share of the benefits.

4.2. The UK Approach to Carbon Pricing

Beginning in 2002, the United Kingdom established a procedure for estimating the global SCC and internalizing the estimates as the marginal cost of emissions for policy appraisals (Clarkson & Deyes 2002). The approach predated that of the IAWGSCC yet was conceptually similar. Although the United Kingdom updated its methodology in 2007 in response to Stern (2006), the (then) UK DECC (2009) began reviewing use of the SCC the following year and issued an entirely different approach beginning in 2009. The result was a significant switch from using the SCC to a target-consistent approach, which is based on estimates of the marginal abatement costs necessary to meet a specific emissions reduction target.

Specifically, the review concluded that:

> The approach, based on estimates of the SCC, should be replaced with a target-consistent approach, based on estimates of the abatement costs that will need to be incurred to meet specific emissions reduction targets. The case for change is motivated by the considerable uncertainty that exists surrounding estimates of the SCC. The change will have the effect of helping to ensure that the policies the UK Government develops are consistent with the emissions reductions targets that the United Kingdom has adopted through carbon budgets and also at an EU and UN level. (DECC 2009, p. 2)

The target-consistent approach recognizes that the United Kingdom sets emission reduction targets in a way that reflects political decision making and international relations. Targets then define a carbon budget, and the marginal values used to evaluate policies are based on estimates of the marginal abatement costs consistent with achieving the implied emission reduction. A key

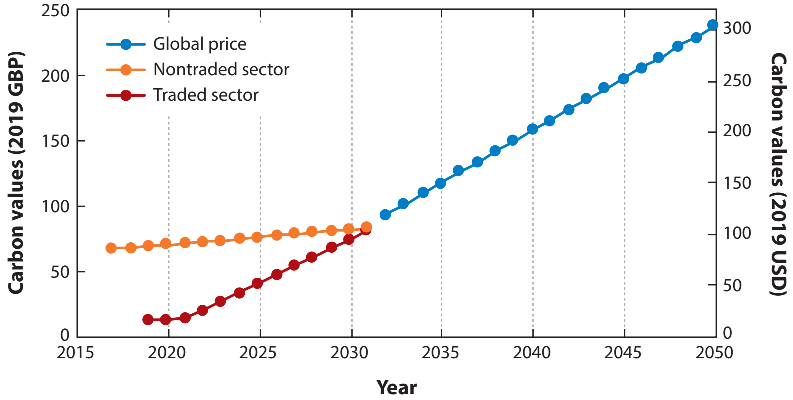

Figure 3

The central estimate carbon values used for UK policy appraisals. Data for the nontraded sector and the global price are from DECC (2009, annex 4). Data for the traded sector are from BEIS (2019, table 1).

element of the target consistent approach, therefore, is estimation of the marginal abatement costs for achieving a given target, rather than the use of IAMs or some other approach to estimate the SCC.

The United Kingdom's long-term carbon budget was first determined by the Climate Change Act of 2008, which set a national 2050 target of reducing emissions by 80% relative to a 1990 baseline. The legislation was then updated in 2019 to set a net zero target by 2050, although it is not clear whether carbon budgets have been updated to reflect the United Kingdom's strengthened ambition.

The United Kingdom's specific approach for carbon valuation differs between the short term and long term. In the short term, there are differences between the traded and nontraded sectors, where the former is defined as those sectors of the economy covered by the European Union Emissions Trading System (ETS). The two sectors are treated differently because, in theory, the ETS establishes marginal abatement costs equal to allowance prices. This means that the allowance prices can be used to infer marginal abatement costs in the traded sector, whereas models are needed to make comparable inferences about marginal abatement costs in the nontraded sectors. A combination of models and prices is used to estimate carbon values for the short term, defined as the period running out to 2030, and estimates for the traded sector are updated on an annual basis to take advantage of observed market trends.[10] For the long term, defined as 2030 onward, it assumed that a comprehensive global trading regime will be in place, and this implies no continuing distinction between the traded and nontraded sectors. The long-term carbon values are based on expectations of an international carbon price derived from global abatement cost models.

Figure 3 illustrates the most recent carbon prices used in UK policy appraisals. Values used for the nontraded sector exceed those for the traded sector, until they converge in 2031 and proceed on the estimated global price path. Note that the values beyond 2030 exceed US estimates of the global SCC using a 3% SDR and increase at a much faster rate. Indeed, the UK carbon price in 2050 is \$314 per tonne compared to the global SCC estimate of \$85.

[10]The most recent updates were in 2018, and price data for all updates are posted at **https://www.gov.uk/government/collections/carbon-valuation--2#update-to-traded-carbon-values:-2018**.

4.3. Challenges for Benefit-Cost Analysis

The political discourse over the SCC could substantially benefit from further research by the academic community on several key conceptual questions. For example, given the very long-term nature of climate change, what is the most appropriate SDR? And where should we draw the boundaries for BCAs of international environmental problems? Focusing on only domestic benefits and costs may be consistent with standard practice of BCA, but it significantly narrows the scope for meaningful progress on addressing global challenges. Indeed, counting only domestic damages ignores the externality that a country imposes on others as well as one of the primary objectives countries have in participating in multilateral climate policy—securing reciprocal emission mitigation efforts from other countries. Finally, are IAMS the most appropriate method for estimating the SCC? Tremendous progress has been made, but there is also an emerging literature that estimates portions of the SCC based on econometric methods.[11]

The UK target-consistent approach avoids many of these difficult issues, but in doing so, it creates a framework that is cost-effectiveness analysis rather than BCA. Rather than using BCA to determine whether policies promote overall economic efficiency, the setting of targets is taken as given from an economics perspective. Analysis using the implied CO_2 values thus provides information about whether a policy will help meet the overall target in a cost-effective way. While this is certainly important, it is worth recognizing that it implies a role for economic analysis that is more about implementation than about setting the overall direction.

5. THE VALUE OF STATISTICAL LIFE

Improving public health motivates a vast array of environmental laws, policies, and programs. This reflects individuals' preferences for better quality and quantity of life, as reflected in the morbidity and mortality outcomes associated with environmental regulations. Indeed, reducing premature mortality risk often represents the largest source of monetized benefits in analyses of environmental regulations (Aldy et al. 2021b).[12]

To monetize the benefits of reducing premature mortality risk, analysts employ the VSL (US EPA 2014), which also goes by "value of a prevented fatality" (HM Treas. 2018) and "value of mortality risk reduction" (Simon et al. 2019). The VSL represents the WTP to reduce a small change in mortality risk, which is then aggregated over a population to produce a cumulative WTP to reduce a statistical fatality. Suppose that in a population of 100,000, each individual is willing to pay $100 for a policy that reduces the risk of dying prematurely by 1 in 100,000. This policy would reduce one statistical fatality (i.e., one unidentifiable individual in this population), and the cumulative WTP (i.e., the VSL) would be $10 million ($100 × 100,000 individuals).

The policy applications of the VSL raise several important questions addressed in the research literature. First, how should mortality risk valuation vary over the life cycle for affected populations? Second, how should the valuation of mortality risk reduction vary across key characteristics of the risk? Third, how should the valuation of mortality risk reduction vary with incomes?

The US EPA has applied a VSL of $9.4 million in Clean Air Act regulatory evaluations since the late 1990s (US EPA 1997, 2014). For example, US EPA (1997) estimated that more than 80% of the nearly $40 trillion in benefits resulting from the Clean Air Act from 1970 to 1990

---

[11]For a literature review, see Dell et al. (2014), and examples of recent studies include those by Burke et al. (2015), Kahn et al. (2019), and Carleton et al. (2020).

[12]Specific references to the US EPA Clean Air Act regulatory impact analyses in Aldy et al. (2021b) are reflected in the database compiled for that paper (**https://doi.org/10.7910/DVN/J2HWDA**).

reflected reductions in premature mortality attributable to declining ambient concentrations of fine particulate matter and lead. Starting in the late 1980s, UK government agencies, notably the Department for Transport, employed a value of preventing a fatality of $1.47 million in its regulatory and policy analyses (Chilton et al. 1999). More recently, the UK Department for Environment, Food and Rural Affairs has employed a value of statistical life year (VSLY) of $56,828 for chronic pollution exposures. This value reflects an assumption that the affected population is in normal health. A lower VSLY value of $29,371 is employed for acute exposures that increase mortality risk for a population assumed to be in poor health (DEFRA 2020). These UK life-year values are about an order of magnitude smaller than the annuitized equivalent of the US VSL.

The US EPA VSL reflects a review and synthesis of 26 studies, 21 of which are hedonic wage studies and 5 of which rely on contingent valuation surveys (US EPA 2014). UK VSLs have typically relied on stated preference studies (e.g., Carthy et al. 1999; Chilton et al. 1999, 2004). UK hedonic wage studies generate VSLs that are about 2.5 times the magnitude of VSL estimates in US hedonic wage studies (Kochi et al. 2006). Viscusi (2008), however, notes that deficiencies in UK occupational fatality risk data and potential econometric shortcomings have contributed to large but unstable UK hedonic wage VSLs. He notes that this helps explain the application of stated preference VSLs in UK policy evaluations. In general, stated preference VSL estimates are less than one-third the magnitude of hedonic wage VSLs (Kochi et al. 2006), and the United Kingdom has relied on stated preference VSL estimates from the publications of Chilton et al. (1999, 2004).

Environmental regulations that reduce premature mortality risk often do so at the extremes of the age distribution: for young children and, even more frequently, for the elderly. To explore how WTP to reduce mortality risk varies with the age of the affected population, scholars have framed the income-risk trade-off in the context of individuals' preference to maximize their own welfare over their lifetimes. An individual expecting large benefits from a future stream of consumption and leisure, which could reflect both life expectancy and expected income, would be willing to pay more to reduce contemporary mortality risk.

An extensive literature illustrates how the VSL varies over the life cycle. Shepard & Zeckhauser (1984) present two extreme cases that illustrate that the value of mortality risk may decline or may take an inverted-U shape over the life cycle. The former case reflects the opportunity for perfect borrowing and annuity markets to enable consumption smoothing throughout the life cycle, which results in life expectancy (which always declines with age) driving a VSL that declines with age.[13] The latter case reflects a world in which the individual cannot borrow against expected future income, and the VSL increases in the early years of adulthood—when income and consumption are growing faster than life expectancy is declining—but eventually peaks and begins to decline when falling life expectancy outpaces growth (and eventual decline) in income and consumption in the individual's elderly years. The bottom line is that at some point in the life cycle, WTP to reduce mortality risk begins to decline for a given population of individuals as they move from middle age to later ages in the life cycle (Arthur 1981, Rosen 1988, Johansson 2002, Murphy & Topel 2006, Hall & Jones 2007, Aldy & Smyth 2014, Córdoba & Ripoll 2017). None of these studies find that WTP to reduce a marginal change in mortality risk is age or life cycle invariant.

The revealed preference literature likewise shows how VSLs take an inverted-U shape over the life cycle. Kniesner et al. (2006), Aldy & Viscusi (2008), Evans & Schaur (2010), O'Brien (2018), and Aldy (2019) illustrate in a variety of labor market and product market contexts how trading off

[13] This is consistent with the VSLY approach employed in recent UK policy contexts described below.

income and mortality risk declines, starting among the middle-aged US population.[14] The stated preference literature has been mixed, with some studies finding an inverted-U shape for VSLs over the life cycle, with others failing to estimate a statistically significant age-VSL relationship (Krupnick 2007).

The VSLY approach taken in the UK regulatory and policy evaluations explicitly accounts for how remaining years of life influence WTP for risk reductions. In some of its BCAs, the US EPA has included a VSLY approach as a sensitivity analysis for its primary evaluations based on an age-invariant VSL [e.g., the regulatory impact analyses (RIAs) for the 1997 ozone and fine particulate matter national ambient air quality standards; see Aldy et al. (2021b)]. This approach estimates the life years (life expectancy) gained associated with the reduction in air pollution and monetizes each life year with the VSLY, an annuitized version of the agency's VSL. More prominently, the US EPA employed a so-called senior discount in an analysis of its 2002 Clear Skies air quality proposal (Aldy & Viscusi 2007), which initially valued mortality risk reductions for the population aged 70 and older at 37% less than for the under-70 population. After intense public criticism, however, the US EPA reverted to an age-invariant VSL.

While mortality risk is often distilled into a single, quantitative measure, such as 1 in 100,000, the qualitative characteristics of the risks may also influence WTP to reduce such risks. Slovic (1987) highlighted how individuals' perceptions of risk vary with not only the quantitative measure but also issues related to controllability, dread, and catastrophic outcomes. To the extent that an environmental regulation reduces the likelihood of a dreaded way of dying, such as cancer, individuals may be willing to pay more than for less-dreaded forms of death (Sunstein 2004, Van Houtven et al. 2008).

In a 2017 assessment of asbestos control regulations, the UK Health and Safety Executive (HSE 2017) employed a VSL for cancer-related mortality of £1.3 million. Although based on the conventional individual welfare VSL used elsewhere in UK government appraisals, this work-related cancer-based fatality valuation measure was further augmented to reflect the cost of medical care, administrative and legal costs, and reduced worker productivity arising from cancer-related mortality. In contrast, the US EPA has not adjusted the VSL for any of the characteristics of risks that its regulations attempt to reduce. It is also worth noting that the unit value of the VSL in this HSE study contrasts with previous studies by this agency that employed a cancer premium reflecting dread risks that effectively doubled the VSL (Andrews & McCrea 1999, Kelly 2008, Baker et al. 2010). However, HSE (2016) updates this thinking, noting a more general lack of empirical support for its earlier approach, and favors using a standard official VSL alongside separately estimated morbidity values associated with work-related cancer illness.

Given that paying for mortality risk reduction today delivers more future consumption and leisure, WTP for such risk reduction would be expected to increase with income (e.g., Cameron & DeShazo 2013). This is evident across revealed preference and stated preference methods and has been subject to a number of reviews (Liu et al. 1997, Mrozek & Taylor 2002, Viscusi & Aldy 2003, Krupnick 2007, Hammitt & Robinson 2011, Doucouliagos et al. 2014, Viscusi & Masterman 2017, Masterman & Viscusi 2018). Meta-analyses of the VSL literature have typically shown income elasticities in the 0.5 to 0.6 range (Liu et al. 1997, Mrozek & Taylor 2002, Viscusi & Aldy 2003), with more recent research confirming this range for developed countries but suggesting an elasticity closer to 1.0 for lower-income countries (Masterman & Viscusi 2018).

[14]Smith et al.'s (2004) study is a notable exception, which finds higher VSLs for near-elderly workers than for younger workers.

In practice, the US EPA has not applied different VSLs with respect to income heterogeneity across a given population at a point in time, but it has increased the VSL with forecast income growth over time when estimating the impacts of some regulations several decades into the future. For example, in the 2011 Cross-State Air Pollution Rule, US EPA used an income elasticity of 0.4 for its central estimate in the rule's BCA. The United Kingdom in effect assumes an elasticity of 1.0, as the VSL is updated in line with changes in GDP per capita.[15]

Finally, how and when should agency analysts update the measure of the VSL in light of the evolution of the literature? Through 2020, the US EPA continued to use a VSL based on its review of a set of 26 dated studies. The average publication date of these studies is 1985, and the most recent paper was published in 1991. The US EPA has only adjusted the VSL from these studies based on inflation over time. None of the labor market hedonic studies employs measures of occupational fatality risk based on the US Bureau of Labor Statistics Census of Fatal Occupational Injuries, which was initiated in 1992. Occupational fatality risk data that predate this fatal occupational injury census suffer from numerous deficiencies that undermine statistical estimation (Viscusi 2004). The contingent valuation studies in this set also predate significant improvements in stated preference methods. Moreover, 5 of the 26 studies address risk-income trade-offs in non-US contexts, which further raises questions about their applicability for US policy and regulatory analysis.

Although it is more recent, the primary source for the value of preventing a fatality in the United Kingdom is a 2004 stated preference survey (Chilton et al. 2004). In each of these cases, government agencies employ fairly dated studies, especially in light of more recent academic scholarship, in monetizing the benefits of reducing premature mortality risk. In the UK case, however, a new primary study of the VSLY is being considered by a number of government departments and agencies that routinely apply monetary values of health impacts in BCA.[16]

6. DISCUSSION AND CONCLUSION

Evaluating the benefits and costs of environmental policy and regulations plays several important roles in policy development. Such analyses highlight opportunities for new policies to address pollution externalities and other market failures related to the environment and natural resources. They can inform the design and implementation of environmental policy by identifying ways to lower costs or target greater benefits. In demonstrating that environmental policy increases social welfare, E-BCA can enhance the political legitimacy of a policy proposal. Along each of these dimensions, the value and credibility of the information depend on the quality of the underlying research evidence.

The United States and United Kingdom have a long history of conducting BCAs of environmental policies and regulations that build on rigorous academic scholarship. E-BCA poses several distinctive challenges where advances in research have expanded the scope of application of informed analysis. We have examined three of these challenges, where an analyst cannot simply rely on posted prices in markets in undertaking an assessment: the weighing of benefits and costs over multiple generations, the value of abating CO_2 emissions, and the benefits of reducing premature mortality risk.

In the context of the SDR, we acknowledge that the debates about the correct long-term discount rate will not be relevant to all environmental BCAs. That is, many (perhaps most) project or regulatory proposals involve benefits and costs over (relatively) short time horizons.

[15] For example, in the context of transport appraisal, DFT (2018, p. 6, paragraph 2.6.5) sets out that the VSL should be adjusted in line with official forecasts of growth in real GDP per capita.
[16] Stavros Georgiou, UK Health and Safety Executive (HSE), personal communication.

The differences between the United States and United Kingdom in their respective approaches to the SDR can be viewed in at least two ways. On the one hand, there appear to be considerable differences in the process of setting the SDR: the opportunity cost of capital and a constant rate (i.e., the United States) as opposed to a declining rate and the return to consumption (i.e., the United Kingdom). On the other hand, practical differences in the outcome in terms of present values can be overstated especially when comparing the UK declining SDR with the lower of the two (constant) SDRs used in the United States. The effective discount rates in the longer term for the United Kingdom, however, are closer to the findings of the survey by Drupp et al. (2018) of academic SDR experts: i.e., a median rate, of 2%, is recommended (within a range of 1% to 3% for the vast majority of respondents).

Intergenerational considerations come to the fore in evaluating the impacts of reducing CO_2 and other greenhouse gas emissions that may reside in the atmosphere and adversely affect the global climate for centuries and millennia. Climate change clearly poses challenges to the use of BCA that warrant more careful analysis. Part of what we aim to show here is that these are frontier issues about how BCA is being used to evaluate and justify some of the most significant environmental regulations in the United States. The lack of clarity in the scholarly literature on how to address some of the key issues, including the choice of the SDR and the global scope of benefits, creates a void in which US policy makers have stepped in to impose alternative analytic assumptions with drastically different implications for the SCC and the ambition of climate change regulations [see the report from the IAWGSCC (2021) for a recent example of these shifting boundaries on interpretation of the evidence for the purposes of policy and appraisal].

Reducing premature mortality risk represents the largest source of monetized benefits in air quality regulatory analyses and the largest single category of benefits across the US federal regulatory program. The policy applications of the VSL reflect how innovations in nonmarket methods—both revealed preference and stated preference techniques—provide the evidence on WTP for environmental and health benefits that are not explicitly traded in markets. In the United States, there has been no meaningful update, with the exception of income elasticity applications in recent years, while in the United Kingdom, there have been considerations of life expectancy (employing a VSLY approach) and dread (cancer premium) that reflect a richer understanding in the academic literature of how individuals value reductions in mortality risk.

Building a robust foundation for the practice of E-BCA by governments requires a detailed understanding of the current state of research and its evolution over time. Advances in the academic frontier related to any key parameter in an E-BCA, including SDR, SCC, and VSL, raise the questions of when and how to update the government's foundation and analytic practice. It is often difficult for an agency to sort through the academic literature and extract the key policy-relevant signals.

There may also be political economy reasons for an agency to maintain the current application of a given parameter in its analysis once it has undergone the process of identifying and selecting it. The evolution of environmental policy may be more predictable, and key stakeholders may be able to form more precise expectations if the key parameters in E-BCAs are not constantly changing. The absence of updating the VSL in the United States, however, is considerable given that the US EPA's measure reflects a survey in which the most recent publication dates to 1991.

In the case of the SDR in the United Kingdom, updating has taken the form of a punctuated and substantial change at the beginning of the 2000s and an absence of revisions since, whereas the United States arguably has been on the verge of updates although never quite crosses that line. In contrast, the US SCC underwent frequent updates during the Obama administration. This reflected the planning to regularly update the SCC as modelers update the damage functions in the three IAMs used by the US government. It also accounts for what is a vibrant and fast-moving academic literature that creates greater value in having an SCC that adjusts to new information over time. The changes over 2010–2016 consistently led to a higher SCC, which also squared with the objective of an administration aspiring to greater emission mitigation ambition. The dramatic reduction in the SCC through the focus on domestic-only benefits and higher discount rates over 2017–2020 coincided with dismissiveness of climate policy by the US government during this period.

Accounting for innovations in the academic literature on the VSL, e.g., explicit life cycle adjustments, would likely reduce the monetized benefits of many air quality regulations and other environmental policies that disproportionately benefit elderly populations. For the leader of an environmental agency, reducing the benefits of environmental regulation may not be an appealing alternative. And claims of disagreements in the literature may be sufficient to maintain the status quo, albeit quite dated, to approach to this issue.

Our approach in this review has been to explore how the practice of BCA in the United States and United Kingdom draws from the research literature on specific, key questions in the evaluation of environmental policies and regulations. Our discussion is also relevant to other countries using E-BCA, although it is important to note that not all countries currently use BCA extensively or have official values such as those we discuss for the United States and United Kingdom, especially for the SCC and VSL.

A number of countries modify their SDRs to account for the long time horizons covered by policies and regulations addressing climate change. France and Norway reduce their discount rates for periods beyond several decades. France is also prominent among a handful of countries making adjustments to the SDR for project-specific (systematic) risks, reflecting, for example, the correlation between the benefits of regulations mitigating climate change risks and macroeconomic growth (Freeman et al. 2018). In some cases, differences between the SDR used in different countries can still be understood straightforwardly in terms of whether the time preference or opportunity cost has been the basis for estimation of these rates (see, e.g., ADB 2013).

The SCC has played an increasingly important role in policy evaluations globally over the past decade. In 2014, 74 national governments endorsed the World Bank's "Putting a Price on Carbon" statement that made specific reference to the use of the SCC in informing the design of climate change policy. A survey of OECD countries by Smith & Braathen (2015) indicates a range of carbon values used in economic appraisal.[17] The average value applied to current CO_2 emissions across 15 separate jurisdictions (not including the United States and United Kingdom) corresponded to an SCC of about $52 per tonne. This average hides some variation, with some of these countries using notably lower values (Chile, Finland, and to a lesser extent Denmark and Ireland) and two countries with notably higher values (Germany, Sweden). Countries also differed in terms of the steepness of the SCC trajectory to 2100.

As a further illustration, Germany has employed a climate cost of $167 per tonne in its evaluation of transportation sector policies, whereas Norway applies an SCC of $104 per tonne in its assessment of policies on nontraded sectors (Howard & Schwartz 2017). Given increasing coordination on policy and regulation, such as on fuel economy standards across North America, Canada and Mexico employed, with modest technical adjustments, the US government's SCC in their regulatory analyses (Environ. Clim. Change Can. 2016, Paul et al. 2017). The International Monetary Fund (IMF) has likewise applied the global SCC estimate from the IAWGSCC (2016) in its assessments of the social costs of fossil fuels (Coady et al. 2019).

[17]This included Canada, Chile, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Israel, the Netherlands, New Zealand, Norway, Sweden, and the European Commission.

Monetizing the benefits of reducing premature mortality risk also plays a role in regulatory evaluations in other jurisdictions. The government of Canada set a VSL of C$6.11 million (in 2004 dollars and adjusted for inflation) based on a similar review of the literature as the US EPA's (Treas. Board Can. Secr. 2007). The European Union employed a VSL of €3.9 million in its evaluation of the benefits of chemical regulations in 2016 (Eur. Chem. Agency 2016). The European Union has also applied a VSLY approach for sensitivity analyses of air quality policies (OECD 2012). In their assessment of the social costs of fossil fuels, the IMF uses an income elasticity of 1.0 to adjust the VSL estimates from developed country contexts for application in developing countries (Coady et al. 2019).

We have emphasized the distinctive importance of the SDR, the pricing of carbon, and the VSL in E-BCAs, but there are other important factors, including (*a*) the nonfatal morbidity impacts of environmental regulation and the suite of nonmarket methods to estimate individuals' WTP to avoid them, (*b*) the role of so-called co-benefits or ancillary benefits (as well as co-costs) in RIAs (Aldy et al. 2021b), and (*c*) the retrospective analysis of rules and policies to evaluate regulatory performance (Aldy 2014, Cropper et al. 2017, Aldy et al. 2021a). Continued scholarship on the topics we focused on here and on these additional issues can inform the future practice of government BCAs and improve the performance of environmental policy.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

LITERATURE CITED

ADB (Asian Dev. Bank). 2013. *Cost-Benefit Analysis for Investment: A Practical Guide*. Manila: Asian Dev. Bank

Alberini A, Cropper M, Krupnick A, Simon N. 2004. Does the value of statistical life vary with age and health status? Evidence from the US and Canada. *J. Environ. Econ. Manag.* 48:769–92

Aldy JE. 2014. *Learning from experience: an assessment of the retrospective reviews of agency rules and the evidence for improving the design and implementation of regulatory policy*. Rep. to Admin. Conf. US, Washington, DC. **https://www.acus.gov/report/retrospective-review-report**

Aldy JE. 2019. Birds of a feather: estimating the value of statistical life from dual-earner families. *J. Risk Uncertain.* 58(2):187–205

Aldy JE, Auffhammer M, Cropper ML Fraas A, Morgenstern R. 2021a. Looking back at 50 years of the Clean Air Act. *J. Econ. Lit.* In press

Aldy JE, Kotchen M, Evans M, Fowlie M, Levinson A, Palmer K. 2021b. Co-benefits and regulatory impact analysis: theory and evidence from federal air quality regulations. In *Environmental and Energy Policy and the Economy*, Vol. 2, ed. M Kotchen, J Stock, C Wolfram, pp. 117–56. Chicago: Univ. Chicago Press

Aldy JE, Smyth SJ. 2014. *Heterogeneity in the value of life*. NBER Work. Pap. 20206. **https://www.nber.org/papers/w20206**

Aldy JE, Viscusi WK. 2007. Age differences in the value of statistical life: revealed preference evidence. *Rev. Environ. Econ. Policy* 12:241–60

Aldy JE, Viscusi WK. 2008. Adjusting the value of a statistical life for age and cohort effects. *Rev. Econ. Stat.* 90(3):573–81

Andrews RM, McCrea P. 1999. UK Health and Safety Executive approach to exposure limit setting. In *Proceedings of the OECD Workshop on the Integration of Socio-Economic Analysis in Chemical Risk Management Decision Making*, pp. 193–202. Paris: OECD

Arrow KJ, Cropper ML, Gollier C, Groom B, Heal GM, et al. 2014. Should governments use a declining discount rate in project analysis? *Rev. Environ. Econ. Policy* 8:145–63

Arthur WB. 1981. The economics of risks to life. *Am. Econ. Rev.* 71(1):54–64

Ashenfelter O, Greenstone M. 2004. Estimating the value of a statistical life: the importance of omitted variables and publication bias. *Am. Econ. Rev.* 94(2):454–60

Atkinson G, Braathan N-A, Groom B, Mourato S. 2018a. *Cost-Benefit Analysis and the Environment: Further Developments and Policy Uses*. Paris: OECD

Atkinson G, Groom B, Hanley ND, Mourato S. 2018b. Environmental valuation and benefit-cost analysis in UK policy. *J. Benefit-Cost Anal.* 9(1):97–119

Baker R, Bateman I, Donaldson C, Jones-Lee M, Lancsar E, et al. 2010. Weighting and valuing quality adjusted life years: preliminary results from the social value of a QALY Project. *Health Technol. Assess.* 14(27):1–162

BEIS (Dep. Bus. Entrepr. Ind. Strategy). 2019. *Updated short-term traded carbon values used for UK policy appraisal (2018)*. Rep., Dep. Bus. Entrepr. Ind. Strategy, London. **https://www.gov.uk/government/publications/updated-short-term-traded-carbon-values-used-for-uk-policy-appraisal-2018**

Black D, Knieser T. 2003. On the measurement of job risk in hedonic wage models. *J. Risk Uncertain.* 273:205–20

Boardman AE, Greenberg DH, Vining AR, Weimer DL. 2018. *Cost-Benefit Analysis: Concepts and Practice*. Cambridge, UK: Cambridge Univ. Press

Burke MS, Hsiang M, Miguel E. 2015. Global non-linear effect of temperature on economic production. *Nature* 527:235–39

Cameron TA, DeShazo JR. 2013. Demand for health risk reductions. *J. Environ. Econ. Manag.* 65(1):87–109

Carleton TA, Jina A, Delgado MT, Greenstone M, Houser T, et al. 2020. *Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits*. NBER Work. Pap. 27599. **https://www.nber.org/papers/w27599**

Carson RT. 2012. Contingent valuation: a practical alternative when prices aren't available. *J. Econ. Perspect.* 26(4):27–42

Carthy T, Chilton S, Covey J, Hopkins L, Jones-Lee M, et al. 1999. On the contingent valuation of safety and the safety of contingent valuation: part 2—the CV/SG 'chained' approach. *J. Risk Uncertain.* 17(3):187–213

CEA (Counc. Econ. Advis.). 2017. *Discounting for public policy: theory and recent evidence on the merits of updating the discount rate*. Issue Brief, Counc. Econ. Advis., Washington, DC. **https://obamawhitehouse.archives.gov/sites/default/files/page/files/201701_cea_discounting_issue_brief.pdf**

Champ PA, Boyle KJ, Brown TC, eds. 2017. *A Primer on Nonmarket Valuation*. Dordrecht, Neth.: Kluwer. 2nd ed.

Chilton S, Covey J, Hopkins L, Jones-Lee M, Loomes G, et al. 1999. Annex 3: new research results on the valuation of preventing fatal road accident casualties. In *Health Costs Due to Road Traffic-Related Air Pollution. An Impact Assessment Project of Austria, France and Switzerland*. Synth. Rep. to WHO Minist. Conf. Environ. Health London, June 1999, Fed. Dep. Environ. Transp. Energy Commun., Bern, Switz. **https://www.ecoplan.ch/download/gks_sr_en.pdf**

Chilton S, Covey J, Jones-Lee M, Loomes G, Metcalf H et al. 2004. *Valuation of health benefits associated with reductions in air pollution*. Final Rep., Dep. Environ. Food Rural Aff., London. **https://web.archive.org/web/20110311114829/http://www.defra.gov.uk/environment/quality/air/airquality/publications/healthbenefits/airpollution_reduction.pdf**

Clarkson R, Deyes K. 2002. *Estimating the social cost of carbon emissions*. Gov. Econ. Serv. Work. Paper 140, HM Treas./DEFRA, London

Coady D, Parry I, Le N-P, Shang B. 2019. *Global fossil fuel subsidies remain large: an update based on country-level estimates*. IMF Work. Pap. 19/89, Int. Monet. Fund, Washington, DC. **https://www.imf.org/-/media/Files/Publications/WP/2019/WPIEA2019089.ashx**

Córdoba JC, Ripoll M. 2017. Risk aversion and the value of life. *Rev. Econ. Stud.* 84(4):1472–509

Cropper ML, Fraas A, Morgenstern R. 2017. Looking backward to move regulations forward. *Science* 355(6332):1375–76

Darmstadter J. 2016. Global benefit-cost analysis in US climate policy. *Resources* 191:34–39

DECC (Dep. Energy Clim. Change). 2009. *Carbon valuation in UK policy appraisal: a revised approach*. Policy Pap., Dep. Energy Clim. Change, London. **https://www.gov.uk/government/publications/carbon-valuation-in-uk-policy-appraisal-a-revised-approach**

DEFRA (Dep. Environ. Food Rural Aff.). 2020. *Air quality appraisal: impact pathways approach*. Guidance, updated March 26, 2021. **https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-impact-pathways-approach**
Dell M, Jones BF, Olken BA. 2014. What do we learn from the weather? The new climate-economy literature. *J. Econ. Lit.* 52(3):740–98
DFT (Dep. Transp.) 2018. *TAG unit A1.1 cost-benefit analysis*. Transp. Anal. Guidance, Dep. Transp., London. **https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/940962/tag-a1-1-cost-benefit-analysis.pdf**
Doucouliagos H, Stanley TD, Viscusi WK. 2014. Publication selection and the income elasticity of the value of a statistical life. *J. Health Econ.* 33:67–75
Drupp M, Freeman MC, Groom B, Nesje F. 2018. Discounting disentangled: an expert survey on the components of the long term social discount rate. *Am. Econ. J. Policy* 10(4):109–34
Dudley SE, Mannix BF. 2014. The social cost of carbon. *J. Fed. Soc. Pract. Groups* 15:14–18
Environ. Clim. Change Can. 2016. *Technical update to Environment and Climate Change Canada's social cost of greenhouse gas estimates*. Rep., Environ. Clim. Change Can., Gatineau. **https://publications.gc.ca/collections/collection_2016/eccc/En14-202-2016-eng.pdf**
Eur. Chem. Agency. 2016. *Cost and benefit assessments in the REACH restriction dossiers*. Rep., Eur. Chem. Agency, Helsinki, Finl. **https://echa.europa.eu/documents/10162/13630/cost_benefit_assessment_en.pdf**
Evans MF, Schaur G. 2010. A quantile estimation approach to identify income and age variation in the value of a statistical life. *J. Environ. Econ. Manag.* 59:260–70
Fraas A, Lutter R, Dudley S, Gayer T, Graham J, et al. 2016. Should the federal regulatory agencies report benefits to Americans from mandated reductions in greenhouse gas emissions? *Resources*, Feb. 8. **https://www.resources.org/common-resources/should-the-federal-regulatory-agencies-report-benefits-to-americans-from-mandated-reductions-in-greenhouse-gas-emissions/**
Freeman M, Groom B, Spackman M. 2018. *Social discount rates for cost-benefit analysis: a report for HM Treasury*. Summ. Rep., HM Treas., London. **https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/935551/Social_Discount_Rates_for_Cost-Benefit_Analysis_A_Report_for_HM_Treasury.pdf**
Gayer T, Viscusi WK. 2016. Determining the proper scope of climate change policy benefits in US regulatory analyses: domestic versus global approaches. *Rev. Environ. Econ. Policy* 10:245–63
Gollier C. 2012. *Pricing the Planet's Future: The Economics of Discounting in an Uncertain World*. Princeton, NJ: Princeton Univ. Press
Gollier C, Hammitt JK. 2014. The long-run discount rate controversy. *Annu. Rev. Resour. Econ.* 6:273–95
Grab DA, Paul I, Fritz K. 2019. *Opportunities for valuing climate impacts in U.S. state electricity policy*. Rep., Inst. Policy Integr., NY Univ. Sch. Law. **https://policyintegrity.org/files/publications/Valuing_Climate_Impacts.pdf**
Greenstone M, Kopits E, Wolverton A. 2013. Developing a social cost of carbon for US regulatory analysis: a methodology and interpretation. *Rev. Environ. Econ. Policy* 7(1):23–46
Groom B, Hepburn C. 2017. Looking back at social discount rates: the influence of papers, presentations and personalities on policy. *Rev. Environ. Econ. Policy* 11(2):336–56
Hahn RW, Dudley PM. 2007. How well does the U.S. government do benefit-cost analysis? *Rev. Environ. Econ. Policy* 1(2):192–211
Hahn RW, Tetlock RC. 2008. Has economic analysis improved regulatory decisions? *J. Econ. Perspect.* 22(1):67–84
Hall RE, Jones CI. 2007. The value of life and the rise in health spending. *Q. J. Econ.* 122(1):39–72
Hammitt JK, Robinson LA. 2011. The income elasticity of the value per statistical life: transferring estimates between high and low income populations. *J. Benefit-Cost Anal.* 2(1):1–29
Hausman J. 2012. Contingent valuation: from dubious to hopeless. *J. Econ. Perspect.* 26(4):43–56
HM Treas. 2018. *The Green Book: Central Government Guidance on Appraisal and Evaluation*. London: HM Treas.
Howard P, Schwartz J. 2017. Think global: international reciprocity as justification for a global social cost of carbon. *Columbia J. Environ. Law* 42:S203–S294
HSE (Health Saf. Exec.). 2016. *Costs to Britain of work-related cancer*. Res. Rep. RR1074, Health Saf. Exec., Bootle, UK. **https://www.hse.gov.uk/research/rrpdf/rr1074.pdf**

HSE (Health Saf. Exec.). 2017. *Post implementation review of the control of asbestos regulations 2012*. Rep. S.I. 2012/632, Health Saf. Exec., Bootle, UK. **https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/598574/post-implementation-review-of-the-control-of-asbestos-regulations-2012.pdf**

IAWGSCC (Interag. Work. Group Soc. Cost Carbon). 2010. *Social cost of carbon for regulatory impact analysis under Executive Order 12866*. Tech. Support Doc., Interag. Work. Group Soc. Cost Carbon, US Gov., Washington, DC. **https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf**

IAWGSCC (Interag. Work. Group Soc. Cost Carbon). 2013. *Technical update of the social cost of carbon for regulatory impact analysis under Executive Order 12866*. Tech. Support Doc., Interag. Work. Group Soc. Cost Carbon, US Gov., Washington, DC. **https://obamawhitehouse.archives.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf**

IAWGSCC (Interag. Work. Group Soc. Cost Carbon). 2015. *Technical update of the social cost of carbon for regulatory impact analysis under Executive Order 12866*. Tech. Support Doc., Interag. Work. Group Soc. Cost Carbon, US Gov., Washington, DC. **https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf**

IAWGSCC (Interag. Work. Group Soc. Cost Carbon). 2016. *Technical update of the social cost of carbon for regulatory impact analysis under Executive Order 12866*. Tech. Support Doc., Interag. Work. Group Soc. Cost Carbon, US Gov., Washington, DC. **https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf**

IAWGSCC (Interag. Work. Group Soc. Cost Carbon). 2021. *Social cost of carbon, methane, and nitrous oxide. Interim estimates under Executive Order 13990*. Tech. Support Doc., Interag. Work. Group Soc. Cost Carbon, US Gov., Washington, DC. **https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf**

Johansson PO. 2002. On the definition and age-dependency of the value of a statistical life. *J. Risk Uncertain.* 25:251–63

Johnston R, Rolfe J, Rosenberger R, Brouwer R, eds. 2015. *Benefit Transfer of Environmental and Resource Values: A Guide for Researchers and Practitioners*. Dordrecht, Neth.: Springer

Just RE, Hueth DL, Schmitz A. 1981. *Applied Welfare Economics and Public Policy*. New York: Pearson

Kahn ME, Mohaddes R, Ng RNC, Pesaran MH, Raissi M, Yang JC. 2019. *Long-term macroeconomic effects of climate change: a cross-country analysis*. NBER Work. Pap. 26167. **https://www.nber.org/papers/w26167**

Kelly C. 2008. *Survey of the value of life/health used in government departments. Summary of findings—report to the inter-departmental group on value of life and health*. Rep., Inst. Transp. Stud., Univ. Leeds, UK

Kniesner TJ, Viscusi WK, Woock C, Ziliak JP. 2012. The value of a statistical life: evidence from panel data. *Rev. Econ. Stat.* 94:74–87

Kniesner TJ, Viscusi WK, Ziliak JP. 2006. Life-cycle consumption and the age-adjusted value of life. *BE J. Econ. Anal. Policy* 5(1):1–36

Kochi I, Hubbell B, Kramer R. 2006. An empirical Bayes approach to combining and comparing estimates of the value of a statistical life for environmental policy analysis. *Environ. Resour. Econ.* 34:385–406

Kopp RE, Mignone BK. 2013. Circumspection, reciprocity, and optimal carbon prices. *Clim. Change* 1204:831–43

Kotchen MJ. 2018. Which social cost of carbon? A theoretical perspective. *J. Assoc. Environ. Resour. Econ.* 5(3):673–94

Krupnick A. 2007. Mortality-risk valuation and age: stated preference evidence. *Rev. Environ. Econ. Policy* 12:261–82

Lavetti K. 2020. The estimation of compensating wage differentials: lessons from the *Deadliest Catch*. *J. Bus. Econ. Stat.* 38(1):165–82

Lee JM, Taylor LO. 2019. Randomized safety inspections and risk exposure on the job: quasi-experimental estimates of the value of a statistical life. *Am. Econ. J. Econ. Policy* 11(4):350–74

Lind RC, Arrow KJ, Corey GR, Dasgupta P, Sen AK, et al. eds. 1982. *Discounting for Time and Risk in Energy Policy*. Washington, DC: Resour. Future

Liu JT, Hammitt JK, Liu JL. 1997. Estimated hedonic wage function and value of life in a developing country. *Econ. Lett.* 57(3):353–58

Louviere JJ, Hensher DA, Swait J. 2000. *Stated Choice Methods: Analysis and Applications*. Cambridge, UK: Cambridge Univ. Press

Lowe J. 2008. *Intergenerational wealth transfers and social discounting: Supplementary Green Book guidance*. Rep., Off. Public Sector Inf., HM Treas., London. **https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/193938/Green_Book_supplementary_guidance_intergenerational_wealth_transfers_and_social_discounting.pdf**

Markandya AM, Pearce DW. 1991. Development, the environment, and the social rate of discount. *World Bank Res. Obs.* 6(2):137–52

Masterman CJ, Viscusi WK. 2018. The income elasticity of global values of a statistical life: stated preference evidence. *J. Benefit-Cost Anal.* 9(3):407–34

Metcalf GE, Stock JH. 2017. Integrated assessment models and the social cost of carbon: a review and assessment of US experience. *Rev. Environ. Econ. Policy* 11(1):80–99

Mitchell RC, Carson RT. 1989. *Using Surveys to Value Public Goods: The Contingent Valuation Method*. Washington, DC: Resour. Future

Mrozek JR, Taylor LO. 2002. What determines the value of life? A meta-analysis. *J. Policy Anal. Manag.* 21(2):253–70

Murphy KM, Topel RH. 2006. The value of health and longevity. *J. Political Econ.* 114:871–904

Natl. Acad. Sci. Eng. Med. 2017. *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*. Washington, DC: Natl. Acad. Press

O'Brien J. 2018. Age, autos, and the value of a statistical life. *J. Risk Uncertain.* 57(1):51–79

OECD (Organ. Econ. Co-op. Dev.). 2012. *Mortality Risk Valuation in Environment, Health and Transport Policies*. Paris: OECD

OMB (Off. Manag. Budget). 1992. *Circular A-94: guidelines and discount rates for benefit-cost analysis of federal programs: appendix C*. Rep., Off. Manag. Budget, Washington, DC, updated Nov. 2015. **https://www.wbdg.org/FFC/FED/OMB/OMB-Circular-A94.pdf**

OMB (Off. Manag. Budget). 2003. *Circular A-4: regulatory analysis*. Rep., Off. Manag. Budget, Washington, DC. **https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/circulars/A4/a-4.pdf**

OXERA. 2002. *A social time preference rate for use in long-term discounting*. Rep. to Off. Deputy Prime Minist., Dep. Transp., Dep. Environ. Food Rural Affairs, London, OXERA Consult., Oxford, UK. **https://www.oxera.com/wp-content/uploads/2018/03/Social-time-preference-rate-for-use-in-long-term-discounting-3.pdf**

Paul I, Howard P, Schwartz JA. 2017. *The Social Cost of Greenhouse Gases and State Policy: A Frequently Asked Questions Guide*. New York: Inst. Policy Integr. NYU Sch. Law

Pearce DW. 1998. Cost benefit analysis and environmental policy. *Oxf. Rev. Econ. Policy* 14(4):84–100

Pearce DW, Atkinson G, Mourato S. 2006. *Cost-Benefit Analysis and the Environment: Recent Developments*. Paris: OECD

Pindyck RS. 2013. Climate change policy: What do the models tell us? *J. Econ. Lit.* 51(3):860–72

Pindyck RS. 2017. The use and misuse of models for climate policy. *Rev. Environ. Econ. Policy* 11(1):100–14

Pizer W, Adler J, Aldy JE, Anthoff D, Cropper M, et al. 2014. Using and improving the social cost of carbon. *Science* 346:1189–90

Revesz R, Greenstone M, Hanemann M, Livermore M, Sterner T, et al. 2017. Best cost estimate of greenhouse gases. *Science* 357:655

Rosen S. 1988. The value of changes in life expectancy. *J. Risk Uncertain.* 13:285–304

Rowell A. 2015. Foreign impacts and climate change. *Harv. Environ. Law Rev.* 39:371–421

Shepard DS, Zeckhauser RJ. 1984. Survival versus consumption. *Manag. Sci.* 30:396–531

Simon NB, Dockins C, Maguire KB, Newbold SC, Krupnick AJ, Taylor LO. 2019. Policy brief—what's in a name? A search for alternatives to 'VSL.' *Rev. Environ. Econ. Policy* 13(1):155–61

Slovic P. 1987. Perception of risk. *Science* 236(4799):280–85

Smith S, Braathen NA. 2015. *Monetary carbon values in policy appraisal: an overview of current practice and key issues*. OECD Environ. Work. Pap. 92, OECD, Paris. **https://www.oecd-ilibrary.org/environment/monetary-carbon-values-in-policy-appraisal_5jrs8st3ngvh-en**

Smith VK, Evans MF, Kim H, Taylor DH Jr. 2004. Do the near-elderly value mortality risks differently? *Rev. Econ. Stat.* 861:423–29

Stern N. 2006. *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge Univ. Press

Sunstein CR. 2004. Valuing life: a plea for disaggregation. *Duke Law J.* 54:385–445

Treas. Board Can. Secr. 2007. *Canadian Cost-Benefit Analysis Guide: Regulatory Proposals*. Ottawa: HM Queen Right Can. **https://www.tbs-sct.gc.ca/rtrap-parfa/analys/analys-eng.pdf**

US EPA (US Environ. Prot. Agency). 1997. *The benefits and costs of the Clean Air Act 1970 to 1990. EPA Report to Congress.* Rep. EPA-410-R-97-002, US Environ. Prot. Agency, Washington, DC. **https://www.epa.gov/sites/production/files/2017-09/documents/ee-0295_all.pdf**

US EPA (US Environ. Prot. Agency). 2014. *Guidelines for preparing economic analyses*. Rep., Natl. Cent. Environ. Econ., US Environ. Prot. Agency, Washington, DC. **https://www.epa.gov/sites/production/files/2017-08/documents/ee-0568-50.pdf**

US EPA (US Environ. Prot. Agency). 2015. *Regulatory impact analysis for the Clean Power Plan Final Rule*. Rep. EPA-452/R-15-003, US Environ. Prot. Agency, Washington, DC. **https://www3.epa.gov/ttn/ecas/docs/ria/utilities_ria_final-clean-power-plan-existing-units_2015-08.pdf**

US EPA (US Environ. Prot. Agency). 2019. *Regulatory impact analysis for the repeal of the Clean Power Plan, and the emission guidelines for greenhouse gas emissions from existing electric utility generating units*. EPA-452/R-19-003, US Environ. Prot. Agency, Washington, DC. **https://www.epa.gov/sites/production/files/2019-06/documents/utilities_ria_final_cpp_repeal_and_ace_2019-06.pdf**

US EPA (US Environ. Prot. Agency). 2020. *Guidelines for preparing economic analyses: review copy prepared for EPA's Science Advisory Board's Economic Guidelines Review Panel*. Draft Rep., US Environ. Prot. Agency, Washington, DC

Van Houtven G, Sullivan MB, Dockins C. 2008. Cancer premiums and latency effects: a risk tradeoff approach for valuing reductions in fatal cancer risks. *J. Risk Uncertain.* 36(2):179–99

Viscusi WK. 2004. The value of life: estimates with risks by occupation and industry. *Econ. Inq.* 42(1):29–48

Viscusi WK. 2008. How to value a life. *J. Econ. Finance* 32(4):311–23

Viscusi WK. 2015. The role of publication selection bias in estimates of the value of a statistical life. *Am. J. Health Econ.* 1(1):27–52

Viscusi WK. 2018. *Pricing Lives: Guideposts for a Safer Society*. Princeton, NJ: Princeton Univ. Press

Viscusi WK, Aldy JE. 2003. The value of statistical life: a critical review of market estimates throughout the world. *J. Risk Uncertain.* 27(1):5–76

Viscusi WK, Masterman CJ. 2017. Income elasticities and global values of a statistical life. *J. Benefit-Cost Anal.* 8(2):226–50

Weible CM, Sabatier PA, eds. 2018. *Theories of the Policy Process*. New York: Routledge. 4th ed.

Weitzman ML. 1998. Why the far-distant future should be discounted at its lowest possible rate. *J. Environ. Econ. Manag.* 36(3):201–8

Weitzman ML. 2001. Gamma discounting. *Am. Econ. Rev.* 91(1):260–71

White House. 2021. *Modernizing regulatory review: memorandum for the heads of executive departments and agencies*. Brief, Jan. 20. **https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/modernizing-regulatory-review/**