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Challenges in applying the paradigm of welfare economics to climate change

Abstract: This paper discusses the challenges inherent in developing benefit-cost analysis (BCAs) of climate change. Challenges are explored from three perspectives: meeting the foundational premises for conducting BCA within the framework of welfare economics, methodological considerations that affect the application of the tools and techniques of BCA, and practical limitations that arise out of resource constraints and the nature of the question, project, or policy being evaluated. Although economic analysts frequently face – and overcome – conceptual and practical complications in developing BCAs, climate change presents difficulties beyond those posed by more conventional environmental problems. Five characteristics of the climate system and associated impacts on human and natural systems are identified that pose particular challenges to BCA of climate change, including ubiquity of impacts, intangibility, non-marginal changes, long timeframes, and uncertainty. These characteristics interact with traditional economic challenges, such as valuing non-market impact, addressing non-marginal changes, accounting for low-probability but high-impact events, and the eternal issue of appropriately discounting the future. A mapping between the characteristics of climate change and traditional economic challenges highlights the difficulties analysts are likely to encounter in conducting BCA. Despite these challenges, the paper argues that the fundamental ability of economic analysis to evaluate alternatives and tradeoffs is vital to decision making. Climate-related decisions span a wide range in terms of their scope, complexity, and depth, and for many applications of economic analyses the issues associated with climate change are tractable. In other cases it may require improved economic techniques or taking steps to ensure uncertainty is more fully addressed. Augmenting economic analysis with distribution analysis or an account of physical effects, and exploring how economic benefit and cost estimates can be incorporated into broader decision making frameworks have also been suggested. The paper concludes that there are opportunities for BCA to play a key role in informing climate change decision-making.

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1 Introduction

Since a firm theoretical framework for BCA based on welfare economics was first established in the 1950s, a large body of literature has developed that provides guidance on how to accomplish the goal of measuring and comparing the benefits and costs of projects, policies, or benefits (e.g., Brent, 2006; Layard & Glaister, 1994; Mishan, 1988; Mishan & Quah, 2007; and other books and articles cited throughout this paper). This literature also thoroughly catalogues and examines the theoretical underpinnings, ethical concerns, methodological challenges, and practical limitations associated with BCA as a tool for analyzing social policy and projects. These considerations have been important drivers in past and ongoing efforts to identify acceptable ethical paradigms, to refine and improve the tools and techniques of BCA, and to explore the importance and implications of alternative choices of key parameters, such as discount rates. For the most part, however, practitioners of BCA are able to operate without continually revisiting the foundations of BCA each time they conduct an analysis.

In recent years, discussions about the challenges in analyzing climate change from an economic perspective have surfaced in both the academic literature and the discussions surrounding climate policy – see, for example, the 2011 symposium in the *Review of Environmental Economics and Policy* (Nordhaus, 2011; Pindyck, 2011; Weitzman, 2011), and papers by Ackerman, DeCanio, Howarth, and Sheeran (2009), Pindyck (2013), and, Weyant (2014). In turn, these discussions have led to questions about an appropriate role for BCA in supporting governmental decision making and informing public opinion regarding climate change policy. Many aspects of climate change, such as multi-generational impacts, interdependent and cascading effects, and uncertainty over projections of key climate variables, conflict with both the underpinnings and the techniques of BCA at a fundamental level. In addition, our incomplete understanding of biophysical and socioeconomic processes and interactions limits our ability to quantify (and monetize) some of the effects of climate change. Together, the characteristics of the climate change phenomenon and our imperfect understanding of the science challenge our ability, as analysts, to conduct robust and complete BCAs.

Analysts have faced analogous challenges in conducting BCAs for environmental problems that have characteristics in common with climate change. For example, the US has produced numerous assessments of the benefits and costs of rulemakings associated with implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer.[1] Since the U.S. EPA finalized its *Regulatory Impact Analysis: Protection of Stratospheric Ozone* in 1988, the agency has made decisions (and seen public debate) regarding a number of potentially controversial issues, including what discount rate to use, the time frame of the analysis, the valuation of changes in mortality and illness, the presence of incomplete information (e.g., does-response relationships), and the quasi-irreversibility of ozone depletion (U.S. EPA, 1988).[2] Over time, economists and other researchers have built a robust and thoughtful body of literature that explores these issues as well as ways to resolve ethical concerns and to address methodological and practical limitations in conducting BCA for environmental problems with characteristics like those of stratospheric ozone protection and climate change.

Much of the concern about the applicability of BCA to climate change has been fueled by discussions surrounding the Stern Review (Stern, 2007), one of the more hotly debated BCAs of climate change (e.g., Dietz & Stern, 2008; Mendelsohn, 2006, 2008; Nordhaus, 2007; Weitzman, 2007; Weyant, 2008). More recently, an ongoing coordinated effort among US government agencies to develop a social cost of carbon (SCC) (Interagency Working Group on the Social Cost of Carbon, 2010; U.S. EPA, 2010, 2011; Weyant, 2014) has drawn considerable attention, including a review of the interagency process by the U.S. Government Accountability Office (GAO, 2014).[3]

While highly visible, efforts such as the Stern Review or the development of the SCC are not the only uses to which BCA is – or might be – put in the service of understanding climate change. It is important, therefore, to

1 The Montreal Protocol on Substances that Deplete the Ozone Layer (a protocol to the Vienna Convention for the Protection of the Ozone Layer) is an international treaty designed to protect the ozone layer by phasing out the production of numerous substances that are responsible for ozone depletion.

2 Personal communications with Mark Wagner and Jessica Kyle, ICF International, October 31, 2014.

3 The SCC has been used to estimate in dollar terms the benefits of rulemakings that reduce greenhouse gases and climate effects, including both rulemakings that directly target carbon dioxide emissions (e.g., car and truck fuel economy standards, energy conservation standards) as well as those that indirectly affect carbon dioxide emissions (e.g., conventional pollutants and air toxics standards).

understand the differential challenges that arise for BCA as the decision and policy-making context changes. Even for climate change the challenges are not one-size-fits-all: not all analyses are as long term or global in scope as the Stern Review. For example, an analysis of the costs and benefits of protecting the North Carolina coastline from sea level rise over the next two decades will not confront the same kinds of distributional and multigenerational concerns as analyses with more extensive scopes and time frames. These differences should be explicitly considered as researchers and policy makers identify a path forward for applied research on climate change, and develop and explore alternative techniques and roles for economic analysis in climate change decision making.

Sections 2 and 3 of this paper discuss how the characteristics of climate change science and impacts pose challenges for the conceptual, methodological, and practical aspects of BCA. Section 2 presents a quick overview and Section 3 offers a more detailed and systematic mapping of climate characteristics and the challenges in performing BCA. Section 4 discusses the implications of the challenges for analyses with different objectives and explores the types of research that are needed going forward. The last section concludes with a set of select observations.

2 Taking the climate challenge: an overview

Benefit cost analysis (BCA) is a tool often used by the public sector as part of project and policy decisions. Developing and then interpreting the output of a BCA in a policy context requires adopting the analytical framework for BCA within the context of welfare economics. It also requires adequate tools and techniques for estimating and aggregating benefits and costs. Last, it requires an acceptance of unavoidable limitations that arise due to incomplete information and other real-world constraints that are often outside the control of the economist conducting the analysis.

Applying BCA to climate change is challenging because of the nature of the science: how the climate system acts over time must be considered along with the ways in which natural and human systems are altered by, and respond to, these changes in climate. Further complicating the challenge are questions about how human and natural systems will evolve during the long time frame over which climate policies are analyzed, including factors such as changing preferences, changing incomes, and the cost and availability of technologies to mitigate climate change or respond to its impacts.

The remainder of this section gives a preview of the concepts and linkages that are explored in detail in Section 3. Section 2.1 summarizes the economic concepts that will be explored in depth in Section 3, and Section 2.2 summarizes the aspects of climate change that challenge the ability of economists to conduct a BCA. Section 2.3 maps the two factors together – economics and climate – providing a reference for the reader to topics that are explored in detail in Section 3.

2.1 The economic paradigm for BCA

Specific challenges posed to BCA by the climate change problem can be explored from three distinct perspectives. First, the interpretation of the results of a BCA for purposes of decision making rests on the foundations of welfare economics. When a BCA involves large changes (such as fundamental changes in the structure of the economy) or Knightian uncertainty, this conceptual basis becomes more visible. Climate change highlights the need to revisit two issues in particular: (1) the distinction between efficiency and equity, and (2) the interpretation of a finding of net benefits as an improvement in efficiency.

Second, the usefulness of a BCA depends on the ability to measure the most relevant values and costs in dollar terms and incorporate these values into the BCA calculus of net present value. This, in turn, requires an ability to quantify these effects and apply valuation or other measurement techniques, and to agree on critical parameters, such as the discount rate. Given the long time frame over which the climate will continue to change, and the diverse (and potentially severe) nature of impacts, methodological challenges are likely to arise for many types of economic analyses of climate change.

Last, any BCA faces practical limitations due to inadequate scientific understanding of the environmental problem, or the availability of data to estimate costs and benefits. Resource constraints can also influence the completeness of an analysis. For some climate-related BCAs, these limitations may be sufficiently severe as to affect the viability of the analysis as a worthwhile contributor to decision making.

2.2 Characteristics of climate change

The challenges in applying the tools of BCA to the circumstances and decisions surrounding climate change arise out of five characteristics of the climate system and the impacts of climate change on human and natural systems, and our ability to understand and anticipate potential future changes. These characteristics are:

ubiquity of impacts, intangibility, non-marginal changes, long time frames, and uncertainty.

First, because climate change is a global phenomenon, it potentially affects everything, everywhere. Thus, its impacts are *ubiquitous* with respect to factors such as geographic region, type of natural system, population group, and socio-economic sector (IPCC, 2013; U.S. Global Change Research Program, 2014).

Second, among this great diversity of climate change impacts, we expect that many will be more or less *intangible*. In other words, there is the possibility of significant impacts, such as loss of cultural heritage, that do not have physical substance, and can be difficult to define in qualitative terms, and even more challenging to measure and quantify.

Third, many of the impacts of climate change are, individually or in aggregate, potentially large or, in economic terms, *non-marginal*. This results, in part, because of the potential for anthropogenic climate change to push the climate system into physical climate conditions unprecedented in human history. Even gradual, marginal shifts in a physical climate variable such as temperature can drive other systems over a threshold into a new equilibrium state; for example, gradual temperature rise eventually leads to ice sheet collapse, which in turn leads to rapid inundation of coastal cities. Such movement to a new equilibrium may be irreversible on characteristic human historical timescales (National Research Council [NRC], 2013), and could include the potential for fundamental changes in human systems (such as cultures lost or relocated), or structural changes to the economy (including income levels and distribution). Moreover, complex interdependencies between climatic, ecological, and human systems may lead to cascading effects that might themselves ultimately be catastrophic, at least within a given region or sector.

Fourth, a great deal of lag is built into the climate system, so that the impacts of both climatic changes, and the policy choices made today, will span *time frames* of decades to generations. This lag exists for several reasons: the long lifetimes of key greenhouse gases, particularly CO_2, in the atmosphere; the strong role of the ocean in regulating the pace of warming; long timescales associated with changes in the major continental ice sheets and associated sea level rise; and the decade-to-century timescales of carbon sequestration in the terrestrial biosphere.

Last, the challenges related to all of the characteristics described above are compounded by fundamental *uncertainty* about the future trajectory of climate over long timescales. This uncertainty results from lack of predictability due to inherent characteristics of the physical climate system (e.g., chaotic dynamics and the natural internal variability of the ocean-atmosphere system); potentially large and poorly understood feedbacks (e.g., biogeochemical) with the distinct possibility of surprise; and the uncertain trajectory of key anthropogenic drivers, the first and foremost of which is greenhouse gas emissions. In addition to scientific uncertainty about the biophysical aspects of climate change, major uncertainties stem from its socioeconomic dimensions as well such as uncertainty about socioeconomic trajectories that affect greenhouse gas emissions and uncertainty about how human systems will respond and adapt to climate change impacts (Heal & Millner, 2014).

2.3 Mapping the economic paradigm and climate change characteristics

Table 1 maps the characteristics of climate change to the challenges of BCA. The conceptual challenges – the distinction between efficiency and equity and the value judgments underlying BCA – have received considerable attention in the climate debate. Equity concerns arise for a variety of reasons. For example, impacts are expected to be very different between countries such as the US, with its well-developed infrastructure and mature economies, and poorer and more vulnerable countries, such as many of the developing economies in sub-Saharan Africa (IPCC, 2012, 2014).

The diversity and magnitude of impacts creates a familiar conceptual challenge for analysts: how to aggregate "apples and oranges." While economists facilitate aggregation by putting everything in the common metric of dollars, and use discount rates to bring future impacts and costs into the present, this approach can be critiqued on philosophical grounds, as discussed in Toman (2014). Moreover, concerns about climate change extend to whether an efficiency approach that sums individual values is meaningful for certain kinds of effects, e.g., potentially catastrophic impacts, or those that are non-economic in nature (such as a loss of culture, or even feelings of security or safety). Underlying the use of BCA is a sense that it is acceptable to ignore these equity or non-economic effects; at the least, the limitations they produce in the application or interpretation of the results are important to understand.

Methodological considerations arise when there is a question of whether researchers now have, or can develop, the tools and techniques that are needed to value and aggregate impacts and costs. Like many environmental problems, climate change includes a variety of types of impacts, including impacts on ecosystems and human health, as well as more market-driven goods and services, such as production or asset values. In some circles, the techniques for valuing some types of impacts are controversial, and economists are continually improving and buttressing the strength of these techniques. Climate change not only pushes the boundaries of economists' abilities to measure intangible or non-marginal

Table 1 Mapping economic challenges and climate change characteristics.

	Challenges for economic analysis		Characteristics of climate change that exacerbate challenges
	Aspect of analysis	**Generic challenge**	
Distinction between efficiency and equity	Equity effects (including intergenerational equity) are not included	Who loses and who gains (or loses less)	Wide-ranging impacts (ubiquity) will result in distributional effects, such as some impacts being greater for poorer countries or poorer populations; impacts will also span current and future generations (time frame)
		Changes in overall distribution of income	Fundamental changes may occur to economies, distribution of income, etc. (non-marginality)
		The types of gains and losses that occur may be important to welfare	Trading off different types of impacts among a broad spectrum of effects (ubiquity) may raise questions of equity, e.g., poverty against property damage
Underlying value judgments	Assumption of individualistic welfare	Alternative systems of value and mechanisms for valuing outcomes and aggregating values	Aggregating individual values in situations where catastrophic events, long time frames, unknown probabilities, etc. are concerned (non-marginality, time frame, uncertainty)
	Omission of non-economic causes of welfare	Effects such as community and culture that are difficult to define, measure, and quantify may be important	Non-economic causes of welfare, which may be important to individuals and society, and result from climate change (ubiquity, non-marginality)
Methodological considerations in conducting economic analyses and BCA	Measuring intangibles	Techniques and the application of those techniques are particularly challenging for impacts involving goods not traded in markets	Wide variety of types of impacts, including those without physical substance or are otherwise difficult to value (intangibility); this includes potential for complete loss of an intangible, such as a whole species (non-marginality)

Table 1 (Continued)

	Challenges for economic analysis		Characteristics of climate change that exacerbate challenges
	Aspect of analysis	**Generic challenge**	
	Valuing future impacts	Choosing a discount rate	Timescale of decades/centuries for impacts (time frame)
	Incorporating uncertainty and risk	Probabilistic uncertainty, deep uncertainty	Some impacts, or the likelihoods of impacts, are unknowable, possibility of surprise (uncertainty)
	Assumption of marginal changes and *ceteris paribus*	Magnitude of scale of change	Economy-wide changes, changes in distribution of income, interdependencies of sectors, structural changes, catastrophic changes (ubiquity, non-marginality)
Practical limitations in applying tools and techniques	Time frame	Stability of preferences, technologies	Assumptions and parameter choices and projecting over long timescales (time frame, non-marginality)
	Completeness and data quality	Across geography Across diverse human populations Across diverse natural systems Across economic sectors and impact categories Across generations	Diverse and widespread impacts (ubiquity, time frame)
	Complexity of the analysis	Interactions, feedback effects	Capturing interactions between sectors (ubiquity)

impacts, but also pushes the boundaries of how to assemble and summarize all the information in a way that adequately represents the future (e.g., the discount rate) and accounts for both probabilistic risk and circumstances in which measurable probabilities do not exist.

Many climate change analyses face an enormous practical challenge: assembling information on a wide range of impacts, geographic areas, and populations; developing underlying projections for populations, migration, the economy, international trade, and ultimately water, food, and energy demand; and parameterizing cost functions and rates of technological change. Not all of these considerations arise for every BCA that is done and, in theory, given sufficient resources and time it is possible that many of the most important data needs could be filled. In general, however, the resources and time required, the likelihood of data gaps or outdated information, and the overall level of difficulty will all increase with the breadth and depth of information included in the analysis.

These economic challenges, the characteristics of climate change, and the mapping between the two, are discussed in detail in Section 3.

3 Taking the climate challenge: an exploration

This section systematically examines the characteristics of BCA that may limit its ability to assess the effects of climate change using a classical welfare economics framework. The challenges are divided into four sections: efficiency and equity, value judgments underlying efficiency in welfare economics, methodological considerations in measuring costs and benefits and calculating net benefits, and practical limitations in conducting BCA.

3.1 Efficiency and equity

Economists generally use the term "efficiency" descriptively, meaning that a project or policy displaying positive net benefits represents a move toward a more "efficient" outcome (i.e., an increase in the size of the economic pie). The greater the net benefits, the greater the additional resources that become available. Thus, while a finding of positive net benefits reflects resource availability and allocation, it does not ensure that society will be better off if the move occurs (Brent, 2006). As a result, proponents and detractors of BCA alike are quick to point out that efficiency is not the only societal goal. Decision makers care not only about the size of the pie, but also how it is distributed (i.e., which groups gain and which lose), as well as what happens to the overall distribution of income (Brent, 2006).

There is no widely accepted recommendation for dealing with distributional considerations in BCA. Most textbooks on BCA point out that BCA can be only a part, although an important part, of the data necessary for informed decisions (see, e.g., Mishan & Quah, 2007). Consequently, they recommend that omissions – such as distributional considerations – be made explicit, and any information that is available be provided. Guidance on conducting economic analysis that has been produced by the U.S. EPA (2014) also recommends that economic analyses include distributional analyses and discuss impacts on groups and sectors that are affected disproportionately and are of particular concern (such as the very young or elderly, low income groups, or minorities). However, some economists recommend that weights be used as part of the process of summing monetary valuations; such weights might be employed not only in connection with equity and distribution, but also to affect the treatment of merit goods, intangibles, or the social rate of discount (Brent, 2006; Florio, 2014). Other economists, however, disagree with this approach, citing factors such as the subjective nature and arbitrariness of most systems of weights, or the political pressures that would be brought to bear on such weights in practice (Brent, 2006; Jones, 2005; Just, Hueth, & Schmitz, 2004; Mishan & Quah, 2007). Some argue that efficiency and equity effects should be reported separately and results reported for different sets of distributional weights (Gramlich, 1990; Jones, 2005).

Global or multi-country analyses of climate change include countries at different levels of development, with very different incomes, infrastructure, and capacity levels, and thus different abilities to adapt or respond to climate change. In many cases, the countries that are at most risk from climate impacts are also those that are least able to respond to and mitigate those risks, thereby exacerbating the distributional impacts (e.g., see Mendelsohn, Dinar, & Williams, 2006). For example, regionally differentiated impacts of climate change on crop production worldwide are expected to worsen if future climate change is significant.

Distributional considerations arise within a country as well. In the aftermath of Hurricane Katrina, for example, questions arose about whose lives and property were protected during emergency planning and response (O'Brien & Wolf, 2010). Similarly, anticipated future increases in extreme heat events in the US would be expected to be felt disproportionately among the elderly and those without adequate access to air conditioning (U.S. Global Change Research Program, 2014).

Not only "who gains and who loses" but also what form the "pie" takes, i.e., what types of gains and losses occur, may limit the normative significance of an efficiency finding (Brent, 2006). For example, the loss of critical ecosystem services in one country may not be easily compared with the cost of protecting the coastline of another country, perhaps one with a well-developed infrastructure

– or with the complete submergence of a small island nation. Particularly if assets are unique or irreplaceable, the underlying premise in BCA that tradeoffs can be made starts to erode.

Moreover, it may be difficult to make efficiency-style tradeoffs because different groups hold different values (e.g., see Adger et al., 2009), as discussed further below. For example, the loss of sea ice in summer months has significance for the Inuit, leaving some people "lonely for the ice" (O'Brien & Wolf, 2010). The appropriate tradeoff between these types of subjective values and more objectively defined economic values is unclear.

3.2 Value judgments underlying efficiency in welfare economics

The interpretation of positive net benefits (an excess of social benefits over losses) as an improvement in efficiency relies on the notion of a potential Pareto improvement[4] for the community, so that a costless redistribution of the benefits could make everyone who is affected by the change better off (Mishan & Quah, 2007). In other words, the gainers under the change could compensate the losers, so that no one is made worse off and at least one person is made better off. The change can thus be interpreted as an increase in social economic welfare or a movement toward a more efficient outcome (Brent, 2006; Mishan & Quah, 2007).[5] This interpretation rests on certain value judgments, two of which are particularly called into question by climate change: (1) an individualistic concept of social welfare, and (2) the judgment that non-economic causes of welfare can be ignored.

Individual welfare. The first value judgment is that, in order to make society better off, we must make individuals better off (Brent, 2006). The individualistic concept of social welfare places a premium on the values of individuals as expressed in market and other behavior. Such behavior may include, for example, voting, altruistic endeavors, and charitable giving. Individual welfare is thus not inconsistent with concern for more than personal welfare or social objectives such as redistribution. In theory, the distribution of income, as well as

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4 A Pareto improvement is one where no one is made worse off, and at least one person is made better off. Positive net benefits, thus, indicates only a *potential* Pareto improvement.

5 Social welfare here means welfare as defined by welfare economics, not by broader notions of welfare or well-being. There is a large body of literature in welfare economics that explores the foundation for different versions of the BCA "test," whether or not compensation is paid, etc. Any general text on BCA will include a discussion of these conceptual issues (e.g., see Boardman, Greenberg, Vining, & Weimer, 2006; Florio, 2014; Mishan & Quah, 2007).

other intangibles (such as the environment or health), can enter individual utility functions, and values can be derived for purposes of BCA.

However, an individualistic interpretation of welfare means that choices or decisions are valued insofar as they allocate resources in ways that maximize individual welfare. Comparisons and tradeoffs among goods and services, outcomes, or changes in the state of the world, will be based on individual values and (in the context of BCA) on aggregation of these values. This interpretation presumes that individuals understand their own values clearly; coupled with consumer sovereignty, it also means that individuals are the best judges of their own welfare. The value placed by an economist on something should be no more or less than that placed on it by the individual (Brent, 2006; Mishan & Quah, 2007).

Not all researchers are comfortable with the concept of individualistic welfare, and some have posited alternatives, such as a focus on societal welfare (i.e., treating society as an entity). An approach favored by Amartya Sen (Anand, Hunter, & Smith, 2005; Sen, 1977, 1999) is to focus on what makes up quality of life, and on the opportunity people have to achieve that life. This approach stresses the capabilities to which a person has access (such as literacy, health, or political freedom), in contrast to the more conventional welfarist approach, which emphasizes individual utility and preferences or access to resources (Anand et al., 2005; Wells, n.d.).

Some authors posit philosophical interpretations of the source of value that are at odds with the individualistic view, including alternatives that focus on the natural world (Sussman et al., 2011; U.S. EPA Science Advisory Board, 2009). Adger et al. (2009), O'Brien and Wolf (2010), and others argue that a values-based approach recognizes that negative material outcomes associated with climate change may be differentially valued by different individuals and groups, and that the implications for action on climate change – particularly with respect to vulnerability and adaptation – could be very different than those arising under a more utilitarian perspective on costs and benefits.

Non-economic sources of welfare can be ignored. Individual well-being depends on goods and services that are consumed; non-economic factors (which might include a sense of community, confidence in the government, or whether or not one feels safe) therefore must have only a small effect on utility, or else must not themselves change by a large amount (Brent, 2006). For most projects or policies, ignoring non-economic sources of welfare may not be unreasonable; but non-economic sources of welfare may be an important consideration for some. For example, the World Bank has long followed the practice of integrating the views of psychologists, environmentalists, sociologists, and others into certain investment decisions, such as large-scale dams (Brent, 2006). Such concerns will be less likely to arise when projects and policies are less far-reaching in scope, so that community values, the structure of livelihoods, or other similar facets of well-being are not altered.

Non-economic goods and services do not contribute directly to financial well-being or wealth, and are not traded in markets, but are nonetheless important to individual welfare. Considerable advances have been made in estimating values for many goods and services that would formerly have been considered intractable to value, such as mortality and morbidity or changes in ecosystem health and services. Thus, in theory, the values of non-economic concerns can be incorporated into a BCA; in practice, valuation is likely to rely almost exclusively on survey techniques that are expensive to implement, and often controversial (as discussed below in methodological challenges). Moreover, some economists believe that some goods – such as national pride, civic participation, community relations, or the alleviation of poverty – are likely to elude all economists' attempts to translate them into unequivocal money valuations, despite progress that has been made in placing some monetary values on them (Mishan & Quah, 2007). Adger et al. (2009) go even further, arguing that climate change impact assessments and adaptation strategies systematically undervalue the involuntary loss of cultural assets that are unique in place and time, since the importance of such assets depends on perceptions and representations of the world, rather than on material values.

3.3 Methodological considerations: measuring costs and benefits and calculating net benefits

Methodologies for estimating costs are well developed, relying on estimates derived from engineering cost studies, market conditions, and other relatively concrete evidence. Even costs, however, can be difficult to estimate when technologies are still experimental or have not been produced and applied widely, when costs into the far future are being estimated, or when broader economic effects or interactions between markets are involved.

Although economists have a well-filled toolbox for conducting valuation, estimating benefits is generally considered to be more difficult than estimating costs (e.g., see discussions of techniques for estimating benefits in Champ, Boyle, & Brown, 2003; Freeman, Herriges, & Kling, 2014; Mitchell & Carson, 1989). Aggregating these benefits and costs over time and across geographic regions and populations adds an additional layer of complexity. The challenges fall into four categories: (1) valuing intangibles (goods and services not traded in markets), (2) ensuring that the treatment of costs and benefits over time is fair to future generations, (3) accounting for probabilistic uncertainty (i.e., risk), and (4) dealing with large-scale changes.[6]

Valuing Intangibles. Some goods and services affected by policies and projects are not traded in markets. As discussed above, the efficiency properties of BCA require a value judgment that such "non-economic" goods and services do not dominate the analysis. In many cases, values for these goods and services (or "states of the world") are more difficult – but not impossible – to measure.

Estimating benefits involves several steps: defining the good or service using a measurable physical unit, determining how the good or service is affected by the project, policy, or other change being analyzed, and then imputing a monetary value to the unit (Brent, 2006; Gamble, Ebi, Grambsch, Sussman, & Wilbanks, 2008; Mishan & Quah, 2007). A rigorous approach to valuation can raise challenges at any stage: how, for example, does one develop a metric quantifying a "sense of community?" Similarly, physical and social scientists may have only a general sense of how the good or service is produced or evolves. Consequently, identifying pathways from climate change to the good or service of interest, and quantifying the outcome of climate change on the metric by which the good or service is measured, can be problematic. The critical challenge to economists comes at the end of the process: assigning a monetary value to the estimated quantitative change in the physical metric of the good or service.

Economists have taken steps to value many of the so-called "intangibles," such as recreation, some of the services provided by ecosystems, or human health risks – in some cases using values inferred from behavior in related or substitute markets, or asking individuals directly to value a change in the state of the good or service. Although used frequently in BCA, these techniques are not without controversy, in part due to the questionable morality of putting a dollar value on something that is viewed as "invaluable," and in part due to criticism and skepticism regarding methods to estimate values using techniques such as surveys.

For climate change, impacts on public health, cultural heritage, environmental quality and ecosystems, and certain distributional effects fall into the category of potentially consequential impacts that are difficult to value in market terms, due to a high degree of heterogeneity in values and preferences (IPCC, 2014, chapter 17). While strides have been made valuing some categories of impacts

6 There are other challenges in the implementation of BCA, including distortions in market prices that complicate the estimation of willingness to pay, such as taxes and insurance for health or property damage. These are not discussed here because they are due largely to the structure of underlying economic and human systems, and so do not necessarily differentially affect BCA with regard to climate change more than other environmental problems or public policies and projects.

relevant to climate change, such as ecosystem services (e.g., see Bateman et al., 2011; De Groot, Wilson, & Boumans, 2002; Polasky & Segerson, 2009) and cultural icons and sites (Navrud & Ready, 2002), significant conceptual and methodological challenges remain in many other areas. Moreover, fundamental skepticism about the usefulness of survey-based non-market valuation methodologies persists; some, like Hausman (2012), go so far as to doubt whether contingent valuation surveys provide any useful information at all.

Economists generally recommend that the appropriate response in cases where "intangibles" cannot be measured (for whatever reason) is to "reveal clearly the area of ignorance," providing physical descriptions where feasible and supplying any indicators of the possible magnitude of damages or benefits [Mishan, 1988; and discussion of this question by Toman (2014)]. This information is then presented side by side with the more rigorous BCA. Mishan (1988) illustrates the problem of intangibles using the classic example of the recipe for making horse and rabbit stew, where the horse represents unquantified (or crudely quantified) intangibles and the rabbit is the carefully monetized costs and benefits. Following a recipe of one horse to one rabbit will result in a stew where the taste of the horse dominates. The larger we believe the horse to be, the less important it is to carefully measure and weigh the rabbit, and the more important it is to understand the pedigree of the horse.

Intergenerational equity and discounting. Analyzing a change that spans multiple decades means including values held by individuals who are not yet born. Particularly challenging are decisions made about discounting and how to value the costs and benefits borne by future generations in a way that is consistent with both efficiency and fairness.[7]

In economics, "equity" refers to the distribution of costs and benefits among different people, or across population groups, and how fair such a distribution can be considered to be. In the context of climate change impacts, equity should be viewed as having two dimensions: intergenerational and intragenerational. The intragenerational dimension that focuses on the distribution of costs and benefits at a single point in time is discussed above in Section 3.1. Here we are concerned with the intertemporal dimension of discounting that focuses on the distribution of costs and benefits over multiple generations. The question of how to discount the very long term is not simply a question of how to make investments rationally, but an ethical question of how to treat future generations.

7 Mishan and Quah (2007) discuss the situation where generations overlap and not all who are affected remain alive during the period of the analysis; they state that, in this case, the interpretation of positive net benefits is as a "*potential* potential Pareto improvement."

Climate change impacts can occur today and continue to be felt far into the future, or impacts may not emerge until some future date. Since the degree of anthropogenic climate change is strongly conditional on human actions, the effects of today's policy choices will have effects far into the future; thus we must make response decisions and incur the associated costs long in advance of any realized benefits. Because the impacts of both climate change and policy choices span generations, the design of policies has enormous implications for intergenerational equity, and changes in the distribution of income across generations.

Because of the long time frame, the choice of discount rate can be crucial to the result [see Weyant (2014)]. The question of what discount rate to use, and how to choose a discount rate, features prominently in the debate about the Stern Review and the SCC [see Weyant (2014)]. There is little agreement among economists over the appropriate discount rate to use in all circumstances and few, if any, economists would characterize climate change as simply another public project or environmental program; consequently, the question of what discount rate to use is not easily resolved, and some argue for presenting streams of impacts rather than aggregating these streams into one number using a discount rate.[8]

Uncertainty. Uncertainty affects a BCA evaluation in two qualitatively different ways (Brent, 2006). The first is uncertainty about inputs into the analysis, such as population, or assumptions about parameters, such as the discount rate, the rate of technological change, or the growth rate of GDP. If the results of the analysis are sensitive to parameter values, then analysts often present the results using a sensitivity analysis that gives the outcome of the BCA under alternative reasonable assumptions about key parameters or inputs. The second type is uncertainty about outcomes or impacts, and is more difficult to address in a BCA context (Brent, 2006).

When faced with uncertainty over outcomes or impacts, most economists instinctively turn to the expected utility framework of Von Neumann and Morgenstern (1953). This formulation assumes a well-defined set of possible states of the world and an exogenously given probability distribution over the consequences, as well as preferences over uncertain choices that can be represented by expected utilities (Heal & Millner, 2014). Probabilistic uncertainty can also be approached using risk analysis techniques, such as Monte Carlo analysis of outcomes (Florio, 2014; U.S. EPA, 2014). Economists may take a Bayesian approach in which probabilities are derived endogenously, a framework that relies on Leonard Savage's

8 The literature on the choice of discount rate for short- and long-term BCA is extensive, and careful consideration of all the theoretical and ethical issues is outside the scope of this paper. For additional discussion of this issue, see U.S. EPA (2014), U.S. OMB (1992) Circular A-94 and subsequent updates, Weitzman and Gollier (2010), and Cropper (2012).

theory of subjective expected utility (Cyert & DeGroot, 1987; Savage, 1972), and so does not require the existence of exogenous probability distributions (Just et al., 2004). However, there is disagreement on how to apply these and other approaches to uncertainty in the context of normative policy analysis. Consequently, the lack of well-defined probability distributions for important damages represents a serious difficulty for the application of BCA techniques (Heal & Millner, 2014).

Questions about the ability of a probabilistic framework to capture our knowledge when information is incomplete, inconsistent, or nonexistent go back at least to Frank Knight (1921), who distinguished between *risk* in the sense of measurable probabilities, and *uncertainty*, which cannot be measured, i.e., is unknown, and perhaps unknowable, at least within the time frame relevant to the analysis. If we adopt that distinction, Knightian uncertainty – which is sometimes referred to as "deep uncertainty" in a climate change context [see Lempert (2014)] – is likely to be most pronounced for precisely the places, times, systems, and circumstances associated with the greatest potential socioeconomic impacts: local and regional spatial scales, extreme events that occur on short timescales, downstream effects of direct physical climate system changes on ecosystems and human systems, and large impacts resulting from crossing tipping points. These realities about the nature of climate change largely preclude the availability of well-characterized probability distributions for the most consequential climate change damages that we might wish to understand.

Knightian uncertainty is not only a methodological concern, but also challenges the normative interpretation of BCA. Knightian uncertainty compounds challenges associated with divergent (but equally valid) worldviews and values when evaluating impacts or benefits. Neither the collection and analysis of data, nor expert elicitation to assess uncertainty, is likely to be productive when key parties to a decision do not agree on the system model, prior probabilities, or what is of value. The task instead is to make decisions despite the presence of deep uncertainty, to communicate how those decisions were made, and to revisit those decisions when more information is available [see Toman (2014) and Lempert (2014)].

Heal and Millner (2014) examine several alternatives to the expected utility approach to decision-making uncertainty, grouped into two categories: "nonprobabilistic approaches" and "multiple priors approaches." Nonprobabilistic approaches, such as maxmin decision rules and minmax regret, require no likelihood information and ignore probabilistic information where it is available. By contrast, multiple priors approaches postulate the existence of multiple probability distributions that are consistent with what we know, and then devise decision rules based on these multiple priors. These approaches make use of likelihood information, but are also more complex to implement (Heal & Millner, 2014).

Heal and Millner (2014) conclude that the "methods we use to evaluate small-scale projects with well-defined, short-run consequences are unlikely to be appropriate for a problem as global, long run, and uncertain as climate change." They argue that there are many promising approaches to decision making under uncertainty, and that economists actually "have an opportunity to develop an inclusive and creative approach to policy analysis that incorporates a variety of viewpoints."

***Marginality,* ceteris paribus*, and scale of change*. Most economic measures of value and cost – particularly those that are inferred from observed market prices and behavior – are developed under the assumption that the changes being evaluated are marginal; i.e., that the changes in quantity being evaluated are too small to affect market prices. The applicability of most measures also relies on assuming *ceteris paribus*: incomes, prices in other markets, the structure of the economy, and other factors affecting values remain unchanged during the time frame of the analysis (Mishan & Quah, 2007). Exceptions to this assumption include survey techniques that estimate values more directly and can be used to analyze larger-scale changes, but even here the assumed "state of the world" from which changes are being evaluated can dramatically alter the magnitude of values that are estimated.

Consequently, researchers often point out that BCA is most useful for partial equilibrium analyses, for which it is safe to assume that changes in other markets, and interactions between sectors and/or the broader economy, can largely be ignored (Brent, 2006). Large-scale changes (including large projects or multiple projects) tend to be difficult to analyze using the partial equilibrium approach of BCA. General equilibrium analyses can be used to capture interactions, but are expensive to use, and so are much less frequently used in practical BCA (Zerbe, 2008).[9]

Some categories of potential climate change impacts would seem to violate the assumption of marginality. For example, low-probability but high-impact catastrophes, such as abrupt collapse of the major continental ice sheets (leading to catastrophic sea level rise), massive release of marine methane hydrates (leading to rapid and extreme global warming), or other "fat tail" behaviors of the Earth system could overwhelm all other elements in a standard economic analysis (Lenton et al., 2008; National Research Council [NRC], 2013; Weitzman, 2009). Similarly, even relatively gradual baseline shifts in basic climate state variables

9 For additional discussions of the use of general equilibrium analysis in the context of BCA, see U.S. EPA (2014). Examples of its application can be found in a series of articles in Part II of Zerbe (2008). Weyant (2014) discusses general equilibrium models in the context of climate change assessment.

like temperature and precipitation could lead to intersectoral interactions and changes in the broader economy that would violate *ceteris paribus*, such as a simultaneous failure of coastal protection infrastructure worldwide once sea level rise crosses a threshold, or a massive collapse of food production in multiple countries for certain levels of warming.

3.4 Practical limitations in conducting BCA

BCA in its ideal form requires that all impacts relevant to efficiency be quantified and monetized. To be complete, BCA should cover all the costs and benefits (whether intangible or tangible) for all affected members of society (Brent, 2006). The challenges to completeness can take multiple forms: estimating costs and benefits for affected members of society who are not yet born but will be born in the time frame of the analysis; estimating values across population groups that may be dispersed geographically and differ in income, age, and tastes; estimating impacts or costs that occur in multiple markets and sectors; and capturing feedback effects or interactions between markets, sectors, and the larger economy.

Even a well-designed and well-executed impact study will have omissions and imperfect information (Boardman et al., 2006). For climate change, data gaps are inevitable, due to the multiplicity of countries, populations, and sectors affected. Moreover, there will be impacts about which we know very little in terms of pathways and effects, and still less in terms of value; consider, for example, political and cultural impacts, or the many hidden costs of disasters (H. John Heinz III Center for Science, Economics, and the Environment, 1999). Complex interactions between sectors, interdependencies between mitigation and adaptation actions, and feedback effects in the economy all contrive to further complicate the measurement of impacts.

Time frame is particularly challenging, from a practical perspective. Estimating costs and benefits over a long period requires projecting valuations and costs into the future and answering difficult questions, such as: What should we assume about future preferences? How will technology and the economy change? The longer the time frame, the more difficult this can be, and may require sensitivity analysis to explore different assumptions about changes in parameters that influence costs and benefits. Technological change or structural changes in the economy may alter costs. The total value of benefits will grow with population and per capita income, and goods and services may become available or become withdrawn from the economy. Tastes may change over time in unpredictable ways, and climate change may influence their evolution. Because the economist cannot foretell such change, s/he has perforce to assume that preferences are stable (or change in foreseeable ways), and project current values into the future (Mishan & Quah, 2007).

No BCA can be truly complete. The process of producing a BCA should be viewed as an "art form" that can produce useful information with the potential to improve decision making (Zerbe, 2013). Climate change analyses are conducted with even less information, and with more Knightian uncertainty than are BCAs conducted for other environmental problems. The unanswered question is to what extent do data gaps, imputed values, or other practical limitations of an analysis impair its usefulness in providing that structure and organization?

4 Implications for economic analysis and decision making

The virtue of a properly conducted BCA is as a "method of structuring conversation and organizing knowledge" (Zerbe, 2013). Consequently, the rigor of economic analysis, its consistency, and the potential for transparency force a careful weighing of the positive and negative consequences of the policy, program, or project under consideration. Despite the challenges, the fundamental ability of economic analysis to evaluate alternatives and tradeoffs is vital to decision making. However, the difficulty of applying the structure and techniques of BCA to climate change analysis has led some researchers to challenge its usefulness in supporting decision-making processes (Ackerman et al., 2009; Spash, 2007; Toman, 2006).

Climate-related decisions span a wide range in terms of their scope, complexity, and depth. As indicated in Figure 1, a range of types of data may be used to provide input into these decisions – from estimates of the costs of greenhouse gas emissions control options or actions to adapt to the impacts of climate change, to analyses that combine cost estimates with estimates of effectiveness or benefits, to more comprehensive and multi-sectoral, global analyses. Thus, recommendations regarding the use of BCA and component costs and benefits for climate change analysis will not be "one size fits all."

For many applications of economic analyses, the issues associated with climate change are tractable. For example, cost information is often readily available via engineering studies or market data; because it is based on observations or other concrete data, its salience and credibility for decision makers is high (Narain, Margulis, & Essam, 2011; Sussman et al., 2013; Watkiss & Hunt, 2012). Cost-effectiveness analysis takes cost data a step further, focusing on finding the least-cost option for meeting a specific target and so avoids many of the

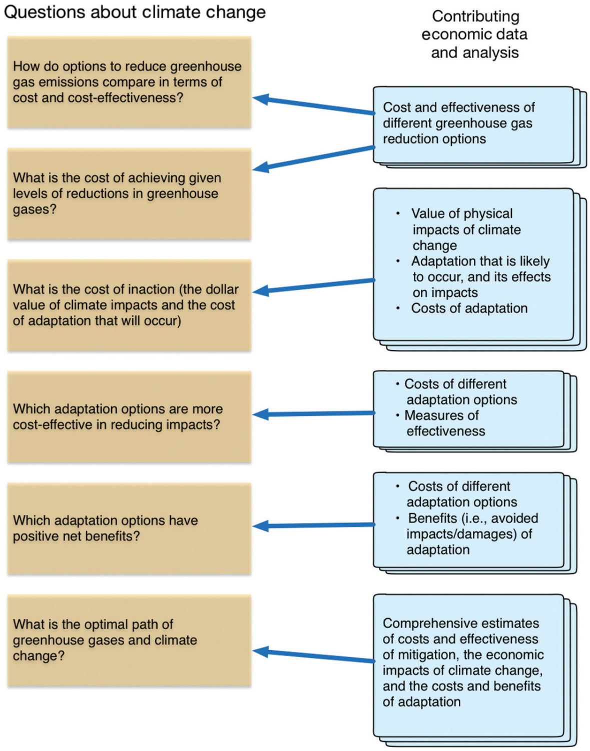

Figure 1 Components of benefit-cost and related analyses of climate change. Climate-related decisions span a wide range in terms of their scope, complexity, and depth; the ability of economic analysis to evaluate alternatives and tradeoffs is vital to decision making. This graphic depicts a range of types of data that may be used to provide input into benefit-cost and related analyses of climate change.

most difficult analytic issues associated with climate change (IPCC, 1995, 2001; Watkiss & Hunt, 2012). Cost-effectiveness can used in situations where metrics of effectiveness or goals can be defined, even though valuation is difficult (e.g., intangibles, ecosystems, health). The shortcoming of cost-effectiveness is that it captures only a single dimension of effectiveness, while other factors, such as technological feasibility, co-benefits, and distributional impacts, may be important to the decision maker (Ranger, 2013; Watkiss & Hunt, 2012).

Similarly, economic studies of climate impacts on market sectors, such as agriculture, forestry, or energy, can use current economic models and methods, although it is important to be clear on the assumptions and limitations in their application to climate change [Neumann and Strzepek (2014)]. Robust uncertainty analyses should accompany such studies to ensure that climate change risks and uncertainties are appropriately captured. Economic assessment of adaptation programs, especially when they are discrete projects at relatively small scales, often use conventional economic methods, although determining how climate change will affect baseline conditions remains a challenge (Narain et al., 2011; Watkiss & Hunt, 2012). Overall, however, economics can clearly inform these types of questions, providing valuable information to decision makers.

Developing more comprehensive BCAs may require improved techniques and tools, more complete specification of physical effects, and additional economic values. The robustness of economic analyses depends, in part, on the reliability of the values attached to climate change effects. As in many economic analyses of other environmental issues, the valuation of effects on human health, ecosystems, and "intangibles" (e.g., sense of community, cultural identity, etc.) will likely be incomplete and difficult. Moreover, although economists have an array of tools to value non-market effects, such valuation has been controversial (Freeman et al., 2014). Consequently, many researchers are concerned that BCA may overlook these types of effects, thereby underestimating benefits that could be a critical piece of the puzzle with respect to climate change (Ackerman et al., 2009). The IPCC's 2nd Assessment Working Group III Report (IPCC, 1995) is a case in point. It was an ambitious effort to conduct "technical assessments of the socioeconomics of impacts, adaptation, and mitigation of climate change over both the short and long term and at the regional and global levels." In particular, the authors' use of mortality valuation that reflected differences in income across countries was criticized by many (see report by Masood, 1995).

There is an ongoing debate in the economics profession as to whether controversial estimates are better than having no estimates at all. Certainly benefit-cost analysts should be extremely cautious about using such estimates. Debates about controversial non-market valuation methods are unlikely to disappear soon. Consequently, improvements in the economic analysis "toolbox" are need to fill gaps in our set of non-market values, develop techniques to generalize and ensure appropriate transfer of values, devise standards for economic analysis of climate change decisions, and improve the clarity, accessibility, and transparency of analytic results.

For more comprehensive and complex questions (e.g., global analyses), economists will need to go even further in augmenting economic analyses with uncertainty, sensitivity, and distributional analyses, and considering alternative frameworks for evaluating different scenarios. The ubiquity and diversity of economic and non-economic measures and values create practical difficulties for BCA (especially completeness), and raise ethical questions about the treatment of distributional consequences. Practical guidance on BCA encourages analysts to supplement monetized benefit estimates with relevant detailed physical information and indicators when monetization is not possible, and to present distributional information in conjunction with economic information (Brent, 2006; Just et al., 2004; Mishan & Quah, 2007; U.S. EPA, 2014). A systematic and rigorous accounting of non-monetized effects (including distributional changes) allows the decision maker to consider these effects along with the quantitative economic analysis.

An example of such an approach is the UN's Experimental Ecosystem Accounting (United Nations, 2014) which seeks to integrate complex biophysical data, flows of ecosystem services, and economic and other human activity. In the public health field, non-economic indicators, such as Quality Adjusted Life Years or Disability Adjusted Life Years have been used in economic studies (Chisholm, 2006; Fox-Rushby & Hanson, 2001; Whitehead & Ali, 2010). Multi-criteria analysis (MCA) allows quantitative analysis of different climate actions against a number of criteria, which could include economic measures such as cost effectiveness (IPCC, 1995, 2001; Watkiss & Hunt, 2012). While assigning weights to different criteria in MCA raises issues, sensitivity analysis can be used to evaluate the impact different priorities have on the result. In essence, MCA can be used to help decision makers discover their priorities. In a similar vein, Toman (2014) describes rationales for a "dashboarding" approach for extending economic frameworks.

The deep uncertainty (synonymous with Knightian uncertainty) associated with climate change is perhaps the most difficult issue for BCA. Some aspects of climate change are uncertain, in the sense that we may never be able to assign probabilities to future outcomes. One proposed solution is to use expert elicitation to develop probabilities for the analysis (Arnell, Tompkins, & Adger, 2005; Morgan & Keith, 1995; Nordhaus, 1994; Titus & Narayanan, 1996). Once probabilities are assigned, traditional economic tools can be used for expected value calculations. Other researchers suggest using non-probabilistic risk management frameworks to address uncertainty such as maxmin, minmax regret, Robust Decision Making (RDM), and climate-informed decision analysis (Hallegatte, Shah, Lempert, Brown, & Gill, 2012; IPCC, 1995; Kunreuther et al., 2013; Lempert, 2014; Ranger, 2013). These approaches use decision criteria that differ from a conventional BCA, but incorporate the underlying cost and valuation techniques and methods of BCA.

The value of economic analysis lies in the provision of a systematic approach to understanding the tradeoffs inherent in decisions. For certain types of analyses (e.g., climate impacts on market sectors, adaptation projects), economics will continue to be an important tool for supporting decisions. For other analyses, upgrades to our knowledge base and techniques can be usefully applied within the economic paradigm. Expanding the traditional BCA toolbox to include non-monetized effects and uncertainty analyses further increases its usefulness. Economic analysis, and the process for conducting that analysis, can play a valuable role in stimulating debate among stakeholders on overall objectives, underlying assumptions and value judgments, although it is unclear at this time how such debates would be resolved. Expanding the analytical process to allow greater participation in decision processes by a variety of stakeholders holds promise for developing improved tools for economists.

5 Conclusions

The list of challenges and controversies associated with economic analysis of climate change is long: the uncertainty associated with climate change projections; the potential for tipping points and consequent non-marginal changes; the wide diversity of impacts across time, geography, and population groups, and resulting distributional effects and intra-generational equity issues; the possibility of low-probability but high-impact catastrophes; and the eternal challenges of non-market valuation and discounting. Many of these are not unique to climate change and many are not limitations of BCA per se, but rather reflect the lack of scientific understanding, which in turn limits the inputs to BCA. It is easy to get lost in these controversies, losing sight of the fact that BCA is moving us in the right direction. For many decisions, BCA practitioners provide useful information using existing state-of-the-art tools and methods. Improving the underlying methods, practices, and components of BCA, as well as expanding BCA to explore additional dimensions of decision making further increases BCA's utility to decision makers. Incorporating components of BCA into other decision analytic frameworks, such as MCA and RDM, and opening the analytical process to stimulate dialog with stakeholders, present additional opportunities for BCA to play a key role in informing climate change decision making.

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