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Improving the practice of economic analysis of climate change adaptation

Abstract: The development of national and sectoral climate change adaptation strategies is burgeoning in the US and elsewhere in response to damages from extreme events and projected future risks from climate change. Increasingly, decision makers are requesting information on the economic damages of climate change as well as costs, benefits, and tradeoffs of alternative actions to inform climate adaptation decisions. This paper provides a practical view of the applications of economic analysis to aid climate change adaptation decision making, with a focus on benefit-cost analysis (BCA). We review the recent developments and applications of BCA with implications for climate risk management and adaptation decision making, both in the US and other Organisation for Economic Co-operation and Development countries. We found that BCA is still in early stages of development for evaluating adaptation decisions, and to date is mostly being applied to investment project-based appraisals. Moreover, the best practices of economic analysis are not fully reflected in the BCAs of climate adaptation-relevant decisions. The diversity of adaptation measures and decision-making contexts suggest that evaluation of adaptation measures may require multiple analytical methods. The economic tools and information would need to be transparent, accessible, and match with the decision contexts to be effective in enhancing decision making. Based on the current evidence, a set of analytical considerations is proposed for improving economic analysis of climate adaptation that includes the need to better address uncertainty and to understand the cross-sector and general equilibrium effects of sectoral and national adaptation policy.

Keywords: benefit-cost analysis; climate change adaptation; economic analysis.

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1 Overview

The most recent assessment report by the Intergovernmental Panel on Climate Change (IPCC) suggests that climate change is increasingly posing wide-ranging risks to human and natural systems, such as human health, water resources, food security, infrastructure, natural ecosystems, and biodiversity (IPCC, 2014a). Strategies to reduce the risks and impacts of climate change include policies and measures that lower greenhouse gas (GHG) emissions (*mitigation*), and actions that make adjustments to natural and human systems to avoid or reduce actual or anticipated impacts from climate change (*adaptation*). Although significant reductions in GHG emissions are needed to avoid dangerous impacts of climate change, it is increasingly recognized that adaptation is also necessary to alleviate negative impacts to human and natural systems that are already occurring or anticipated, given the existing accumulation of GHGs in the atmosphere and the long lag time in the climate system responses to altered GHG levels (IPCC, 2007, 2014a).

A growing number of national and sectoral climate adaptation plans and strategies have been developed. The majority of Organisation for Economic Co-operation and Development (OECD) countries have now produced strategies to coordinate adaptation at the national level (Mullan, Kingsmill, Kramer, & Agrawala, 2013). At the local level, adaptation planning is also emerging in response to experienced extreme events (e.g., flooding, storm surges, and droughts) and projected future risks from climate change. These national and local strategies are typically devised with limited quantitative and systematic assessments of the costs, benefits, and tradeoffs of alternative strategies (OECD, unpublished).

Increasingly, decision makers are requesting information on the economic damages of climate change as well as the costs and benefits of alternative actions to inform their decisions on how to manage the risks resulting from climate change. In the US, for example, in response to Hurricane Sandy the federal government has established guidelines for “comprehensive, forward-looking and science-based analysis” for infrastructure investments that consider a broad range of information and best available data, including “projected future risks from climate change, anticipated impacts, and costs and benefits of alternative investment strategies” (Hurricane Sandy Rebuilding Task Force, 2013). In a recent Executive Order to enhance resilience of the nation to the impacts of climate change, President Obama reiterated the need for risk-based decision making, including information on the costs and benefits of adaptation measures (Executive Order No. 13653, 2013). Internationally, economic analysis, including benefit-cost analysis (BCA), is also considered to be important to systematically evaluate and prioritize adaptation measures and to understand the scale of adaptation investment needs (Chambwera & Stage, 2010; Economics of Climate Adaptation, 2009; OECD, 2008; Stern, 2007; United Nations Development Programme, 2004; United Nations Framework Convention on Climate Change [UNFCCC], 2011). Looking to the future, continuing pressures on public finances suggest that there will be a continued need to use tools such as BCA to justify and prioritize adaptation investment decisions.

Economic analysis of climate adaptation is still in its infancy. In this paper, existing economic tools are examined and their applicability evaluated for climate change adaptation analysis, with attention paid to where practices need to be strengthened to support sound adaptation decision making. A conceptual discussion of the use of economic information and BCA in the context of climate risk management is followed by a review of recent methodological developments and applications of economic analysis relevant to climate change adaptation decisions at the federal, state, and local levels in the US and in selected OECD countries. Based on the current evidence, a set of analytical considerations is provided to enhance economic analysis to support deliberative adaptation decision making.

This paper focuses on economic analysis in the context of public sector, planned climate change adaptation decision making. However, the insights and tools discussed may also be useful for adaptation decision making in other contexts. The economic analysis of climate impacts is not a focus of this paper, but such information and analysis are critical to understanding the climate risks, motivating actions, and informing the BCA of adaptation efforts. Numerous efforts are underway that use internally consistent analytical frameworks to develop estimates of climate change impacts and risks to inform climate change mitigation and adaptation decision making at various levels (e.g., see reviews by Neumann & Strzepek (2014) and by Weyant (2014); Gordon, 2014; Interagency Working Group on Social Cost of Carbon, 2013; Waldhoff et al., 2014). The following topics, also important aspects of economic analysis of climate change, are not addressed in this paper but discussed extensively elsewhere: the costs of adaptation from a top-down perspective to understand the adaptation financing needs (e.g., see UNFCCC, 2007; World Bank, 2010); the synergy and tradeoffs of climate change adaptation and mitigation (see IPCC, 2007; Klein et al., 2007; OECD, 2008; Tol, 2005); and the economics of climate change mitigation (e.g., see Clarke et al., 2009; IPCC, 2014b; Kriegler et al., 2014; Nordhaus, 2010; Weyant, 2014).

2 Economic analysis of climate adaptation: contexts and conceptual issues

Adaptation actions encompass a broad range of measures and strategies. Furthermore, adaptation measures tend to be highly region- and context-specific. Various framings of adaptation have been proposed (see Burton, 1996; Cimato & Mullan, 2010; OECD, 2008; World Resources Institute, 2007). Adaptation actions can be distinguished as being private or public, autonomous or planned, and stand-alone or integrated, and can vary in their timing, approach, and scale. Table 1 illustrates a range of adaptation approaches and examples. Autonomous adaptation refers to actions taken "in response to experienced climate and its effects, without planning explicitly or consciously focused on addressing climate change" (IPCC, 2014a). Planned adaptation results from deliberate policy decisions made to manage anticipated risks arising from climate change. Within the public sector, it can be implemented through measures such as regulations, standards, and investments. Planned adaptation is particularly relevant for decisions with long time frames, such as infrastructure design. Adaptation measures can also be standalone, or integrated with existing policies, programs, and operations (i.e., "mainstreaming"). OECD countries have tended to adopt mainstreamed approaches to adaptation policy, reflecting the interconnections between climate change and institutional, social, and environmental stimuli (Mullan et al., 2013).

Table 1 A summary of adaptation approaches and examples.

Adaptation approach	Examples
Technological approach	Drought-resistant crop varieties Hardening of infrastructure
Informational approach	Early warning systems Sea level rise mapping
Regulatory approach	Building codes Design standards
Market or financial mechanism	Payments for ecosystem services Subsidies Insurance
Behavioral intervention	Agricultural extension services Training programs
Land-use planning	Zoning Watershed and land use management
Ecosystem-based approach	Wetland restoration Beach nourishment

In addition, adaptation can occur at different scales – from local, project-level measures, to sectoral or regional planning, and national policy (e.g., research and development).

A number of methodological and practical challenges have hindered the uptake of economic tools to support climate change adaptation assessments. Economic analysis of adaptation measures requires information on impacts – both physical and economic – that are distributed unevenly across time, location, and systems, and can potentially be non-marginal (e.g., catastrophic outcomes as a result of ice sheet collapse) and irreversible (such as species losses). Analyses that explore climate impacts across a range of sectors and impact categories using internally consistent frameworks and scenarios have just begun to emerge, and information is still limited for informing adaptation efforts [see a review of recent sectoral-level studies of climate change impacts in Neumann & Strzepek (2014)]. In addition, the costs of adaptation are only developed for limited adaptation options and impact categories, using different methodologies, climate scenarios and time frames, making comparison and aggregation challenging (see a recent review of climate adaptation costs in the US by Sussman et al., 2014a). Moreover, uncertainties associated with climate change – related to both the dynamics of the natural climate and biophysical systems and how the future social and economic systems unfold – pose significant challenges to predicting when and where the impacts of climate change may occur (see Heal & Millner (2014) and Sussman, Weaver, & Grambsch (2014b) for systematic reviews of uncertainty of climate change and challenges to economic analysis). These uncertainties are exacerbated at regional and local levels where many adaptation actions would take place.

Existing economic tools and best practices provide useful techniques and building blocks for performing economic analysis of climate adaptation measures. They also can address specific analytical issues, such as the establishment of baselines, valuation of different categories of costs and benefits (such as for health and safety), analysis of distributional impacts, choice of discount rates, and treatment of risks and uncertainty (e.g., Brent, 2006; Florio, 2014; HM Treasury, 2011; Office of Management and Budget, 2003; U.S. Environmental Protection Agency, 2014; Zerbe, Davis, Garland, & Scott, 2010). BCA tools are beginning to be used to evaluate and support adaptation efforts in different contexts, and various frameworks have been proposed to address issues specific to the economic analysis of adaptation (e.g., Chambwera & Stage, 2010; Economics of Climate Adaptation, 2009; Stern, 2007; UNFCCC, 2011; World Bank, 2010). These models provide a useful starting point to improve the foundation and applications of BCA of climate change adaptation.

The choice of economic tools for evaluating climate change adaptation measures depends upon the decision contexts: the location, scale, approach, and timing of the actions. The applicability and robustness of BCA to evaluate adaptation decisions vary by sector. For some sectors and decision-making contexts, economic tools can be readily used and sufficient data are available to understand the welfare impacts of adaptation options. For example, for infrastructure decisions, standard engineering-based methods can be used to estimate the cost of climate resilient design; the expected benefits of the measure can be calculated based on projected probability of climate event occurrence (e.g., flooding) and estimates of avoided repair cost, and direct and indirect economic losses from service interruptions. In other situations, economic analysis may be more challenging, such as when adaptation options involve policy changes or ecosystem-based measures.

The use of a mainstreamed approach to adaptation in OECD countries also has implications for the use of BCA for appraisal of policies and programs. It may not be possible, or necessary, to separate out the costs and benefits of the adaptation component of the policy or program under consideration. Instead, analysis should evaluate the overall welfare implications of different policy options when climate change is taken into consideration.

3 Applications of BCA for climate adaptation: current evidence base

Economic tools – including BCA – have been used extensively to evaluate policies, programs, and projects. In this section, we review applications and best practices of BCA for public sector decision making in the US and selected OECD countries (the UK and Mexico). The review is not comprehensive, but rather is intended to capture significant developments and applications of BCA that are relevant to climate change adaptation decision analysis either because the methods, techniques, and best practices can be applied to analysis of climate adaptation, or the decision contexts are climate-sensitive and already consider climate variability. The use of economic tools for climate adaptation assessment is still in early stages of development and we include emerging policies and applications where available. The following section, drawing on this review, discusses issues with applying BCA to climate adaptation and analytic practices that could address those challenges. Economic analysis of climate adaptation in developing countries is not a focus of this article, but is reviewed briefly and discussed in Text Box 1.

TEXT BOX 1 Application of BCA to evaluate climate adaptation in developing countries.

We focus mainly on the use of economic tools and BCA to evaluate climate adaptation in OECD countries. Internationally, however, economic analysis frameworks and applications – including BCA – are also emerging at national, sectoral and local levels (e.g., Economics of Climate Adaptation, 2009; World Bank, 2010; Watkiss, Downing & Dyszynski, 2010; Inter-American Development Bank, 2014). The development and applications of economic analysis and tools in developing countries are driven mainly by the needs to understand the magnitude of adaptation investments and financing gaps for international development aid. Analytical considerations and the implementation of economic analysis in the developing country context are more complex, complicated by data limitations and other societal and institutional considerations (e.g., sustainable development, poverty reduction). The challenges noted for BCA in the developed country context are further exacerbated within the developing country context due to the overall greater vulnerability and lesser adaptive capacity to climate-change-related risks. Within the scope of sustainable development, valuing non-market goods and services (e.g., ecosystem services) is argued to be more important in the developing country context (e.g., Pearce, Atkinson, & Mourato, 2006). Furthermore, policies that address climate change adaptation directly may be compete with social policies that address other key aspects of sustainable development. This paper does not address issues in the developing country context, but acknowledges that additional considerations are needed for evaluating adaptation response in developing countries.

3.1 BCA policies and applications in the US

At the federal level in the US, BCA is required during the planning phase of assessing major regulatory actions and federal investment projects. The Office of Management and Budget (OMB)'s Circular A-4 "Regulatory Analysis" establishes guidance to federal agencies for evaluating the impact of proposed regulatory actions (OMB, 2003), including those that address environmental externalities such as GHG emissions. BCA is a primary tool used for regulatory impact analysis. Circular A-4 outlines analytical considerations and best practices for regulatory BCA, including the development of baselines, methods for obtaining costs and benefits (including for health and safety outcomes), choice of discount rates, and treatments of uncertainty. Circular A-4 requires agencies to use discount rates of 3% and 7% in regulatory BCA, each representing the average intragenerational social rate of time preference for consumption and the average before-tax rate of return to private capital, respectively. The ethical consideration of intergenerational discounting is also discussed in the Circular, and lower but positive discount rates are suggested for BCA with long time frames. In addition, Circular A-4 outlines a number of guiding principles for good practices, including analytical transparency and full disclosure of uncertainty, and suggests quantitative analysis of uncertainty in the BCA when possible, such as using estimated probability distributions around key variables.

The OMB Circular A-94 "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs" (OMB, 1992) is largely superseded by Circular A-4, particularly for regulatory impact analysis. However, discount rates in Circular A-94 are still followed by some federal agencies for investment programs. OMB publishes updated discount rates each year, reflecting interest rates on Treasury notes and bonds. For example, the current 30-year real interest rate for cost-effectiveness analysis is 1.9% (OMB, 2013). As a default position, Circular A-94 states that a real discount rate of 7% should be used as a base case for BCA.

In addition to regulatory impact analysis, BCA has also been used extensively to evaluate programs and project-level investment decisions in the US, especially those that seek federal funding. At the federal level, the applications and practices of BCA for program or project evaluation vary considerably by agency and sector, driven by statutory requirements, institutional policies, and capacity. Some federal agencies require formal BCA to justify funding allocation and prioritize project investment decisions (e.g., transportation, disaster management, water resource programs); in some other cases, BCA plays a more limited role or is absent in project evaluation and selection. However, BCA or components of BCA are often applied to evaluate the costs, benefits, or cost-effectiveness of policies and programs in situations where BCA is not formally required.[1] Compared with the BCAs of major regulatory actions that undergo reviews by interagency panels and the public, the BCAs of federal programs and investments are less transparent and not easily accessible for evaluation.

Building on regulatory and program BCAs, BCA of climate resilience investments is emerging. The next sub-sections present selected examples of BCA approaches from three federal programs: disaster management, transportation infrastructure investment, and water resources management. A brief discussion of BCA applications for climate adaptation at the state and local levels follows.

3.1.1 FEMA disaster management programs

The Federal Emergency Management Agency (FEMA) requires that applicants to its hazard mitigation grant programs conduct BCA using FEMA-approved meth-

1 Examples of BCA applications by federal agencies are numerous. To give a few examples, the Natural Resources Conservation Service of the U.S. Department of Agriculture provides economic data and BCA tools to help farmers and ranchers to improve conservation and agricultural operations; the U.S. Department of Health and Human Services provides databases and tools to evaluate a range of health policy issues, including cost and quality of health services, and outcomes of treatments.

odology (FEMA, 2009, 2011a). Proposed projects will need to demonstrate a benefit-to-cost ratio greater than one to qualify for FEMA funding. To facilitate the use of BCA, software tools are developed for major natural hazards, including floods (riverine and coastal), hurricane winds, tornados, and wildfires. These tools consist of modules that incorporate hazard risk and frequency data to assess projected costs and benefits of hazard mitigation projects.

FEMA's BCA tools also include modules that provide standard values for commonly incorporated cost and benefit categories. The cost categories in the FEMA BCA tools are standard in engineering analysis, including equipment, labor, materials, and subcontract costs. A range of benefits and values are developed for the BCA tools, including avoided casualties, building damage, content loss, displacement cost, and losses in services (e.g., electric power; potable water; wastewater service; access to roads and bridges; and police, firefighting, and hospital services). All FEMA projects use a discount rate of 7% and value costs and benefits over a standardized project useful lifetime, based on project type. Recently, FEMA began to encourage incorporation of the valuation of environmental and ecosystem services in its BCA for certain funding programs (FEMA, 2013b). To facilitate the inclusion of valuation of environmental services in its BCA, FEMA provided a set of recommended values for selected ecosystem services (such as aesthetic values, air quality benefits, erosion control, flood hazard reduction, and recreation values associated with green open space and riparian zones) based on the literature, agency analysis, and private studies.

The FEMA BCA tools, using standard values, have facilitated applications of BCA in the development and prioritization of hazard mitigation projects, many of which are implemented at the state and local levels where resource and expertise are limited for carrying out detailed BCA analysis. In addition, the FEMA BCA methodology and tools (or components of tools, such as the standard values of costs and benefits) are also adopted by other federal agencies in their BCA guidance and applications. The use of standard values in such cases reduces the burden placed on BCA users and may assist in increasing uptake.

In a recent review of FEMA's implementation of BCAs, Rose et al. (2007) conducted an independent analysis of the expected benefits of a statistical sample of the FEMA hazard mitigation grants for earthquake, flood, and wind hazards between 1993 and 2003. The benefit categories included a range of direct (reduced property damage, service interruption), indirect (secondary economic impacts), non-market (environmental services), and human health impacts. They found that on average the benefit-cost ratio for FEMA's mitigation grants is about 4:1 and the average ratio varies by hazard type (e.g., 1.5:1 for earthquake to 5:1 for flood mitigation). These estimates were found to be robust against a range of discount rates (0–7%) and other key parameters.

FEMA recognized the limitations of relying on historic hazard damage and frequency to project potential future risks in the face of climate change, and has begun to incorporate future climate change risks – such as projected long-term sea level rise and flooding risks of a minimum of 75 years – in its BCA tools, particularly in relation to infrastructure projects (FEMA, 2011b, 2013a). Currently, FEMA is in the process of updating its guidance to states on hazard mitigation planning (FEMA, 2014). The proposed update includes specific requirements for states to account for and address the impacts of future climate change in mitigation planning. Integrated risk assessment methods are suggested to identify hazards, vulnerability, and losses and to prioritize actions to increase statewide resilience to hazards, including the future climate change.

3.1.2 DOT transportation grant programs

The Department of Transportation (DOT) requires BCA for transportation infrastructure investment projects that seek funding from its grant programs (DOT, 2013a). In recognition of the needs for improving funding decisions that prioritize projects that generate national benefits, DOT uses BCA as a selection criterion for its Transportation Investment Generating Economic Recovery (TIGER) grant program (DOT, 2013b). The guidance document outlines key considerations (e.g., project baselines, alternatives, affected populations, types of impacts, and benefits) for preparing BCA for transportation infrastructure projects and refers to the OMB circulars A-4 and A-94 for further guidance. In addition, DOT has developed guidance on valuation methodologies and standard monetized values for different categories of costs and benefits, such as the value of statistical life, injuries, travel time, property damage, and emissions (DOT, 2014). DOT requires BCA using a real discount rate of 7%, but suggests that applicants may also provide an alternative analysis using a real discount rate of 3% for projects with alternative use of funds for other public investments.

Recently, as a response to Hurricane Sandy recovery, the Federal Transit Administration (FTA) of DOT established funding programs for climate-resilient transportation infrastructure projects in regions affected by Hurricane Sandy (FTA, 2013). BCA is required of applicants to demonstrate the benefits and costs of proposed projects. The BCA methodology and values developed by FEMA and DOT discussed above are suggested for analysis. The evaluation considers both quantitative measures of future disaster risks and avoided damages (e.g., the potential repair and emergency response cost, losses due to service interruption, asset damages, and travel time delays) as well as quantitative factors identified by the applicant. The proposals are evaluated entirely based on their climate resilience benefits and the ability of the project sponsor to carry out the project.

3.1.3 Water resource planning and investments

The U.S. Army Corps of Engineers (ACE), the principal agency responsible for development and evaluation of water resource projects (including those related to storm resilience, wetland restoration, and flood prevention), was guided by requirements outlined in the "Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies" (U.S. Water Resources Council, 1983). This set of principles and guidelines required ACE to evaluate the effects of potential projects on national and regional economic development, environmental quality, and other social effects. However, the national economic development impacts were the only category required in the BCA. Other impacts may be displayed in monetary, numeric, or non-numeric terms. The 1983 principles and guidelines also established the discount rate for BCA each year; the rate can fluctuate only by one percentage point from year to year. The current discount rate for water resources projects in 2014 is set at 3.5%.[2] The ACE employs a cost-effectiveness criterion for environmentally beneficial projects, given the challenges in measuring ecological, cultural, and aesthetic attributes in monetary terms.

Recognizing the strong emphasis on economic outcomes of the 1983 principles and guidelines, and the unfavorable environmental consequences of some water development projects, the 1983 document is currently being updated and will be replaced by the "Principles and Requirements for Federal Investments in Water Resources" (Council on Environmental Quality, 2013). The proposed new guidance establishes a common framework for evaluating federal investments in water resources and requires that such investments "strive to maximize public benefits, with appropriate consideration of costs." The common framework intends to enhance analytical consistency in evaluating water resource

2 Current discount rate for water resource projects in the United States is retrieved from: http://planning.usace.army.mil/toolbox/library/EGMs/EGM14-01.pdf.

investments and allows for comparison among potential federal investments to facilitate the decision-making process.[3]

The framework emphasizes an "ecosystem services approach" that evaluates – in addition to direct economic impacts – environmental and social goals, and allows for consideration of both quantified and un-quantified measures, and both monetary and non-monetary effects. The new 2013 principles and requirements also necessitate the use of "the best available, forward-looking scientific data at the commensurate level of detail to characterize future risks." Risks and uncertainty, including those associated with climate change, are discussed in detail.[4] Given the challenges of valuing ecosystem services and the varying practices among federal agencies; however, the effectiveness of this new approach set in the 2013 principles and requirements remains to be determined.[5]

Weather-related risks are considered in the ACE's analyses. In general, historic risk data are used to derive probability distributions for future events using best available information and judgment. Climate change risks are increasingly being considered and incorporated in the ACE's analyses. Recently, the ACE is mandated to incorporate the direct and indirect effects of future sea level change in its operations, analysis, and project development (U.S. ACE, 2013).

3.1.4 US state and local experience with BCA

At the state and local levels, adaptation planning and response to climate risks vary significantly, driven largely by vulnerability, past experience with extreme events, and resource availability. Federal resources are often relied on by states and local planners to understand and communicate climate change risks and vulnerabilities, and to evaluate tradeoffs of alternative courses of actions. Federal funding opportunities and associated evaluation requirements are often the driving force for the development of BCA for projects at the state and local levels. Requirements for and applications of BCA at the state and local levels are often simplified. For instance, qualitative assessments (such as assignment of high, medium, and low instead of quantitative estimates) are used to evaluate alter-

3 The agencies covered by the guidance are the Army Corps of Engineers, Environmental Protection Agency, Commerce, Interior, Agriculture, FEMA, and Tennessee Valley Authority.

4 Specifically, the 2013 principles and requirements document suggests transparent discussion of the nature, likelihood, and magnitude of risks in the analysis, and the need for improving data and methods where uncertainties are significant.

5 At the publication of this paper, the guidance document that would provide more specifics on the implementation of the principles and requirements has not been finalized.

native strategies in some cases (see, e.g., State of Oregon, 2010). Research on the economic damages of extreme weather events and the costs and benefits of adaptation actions is increasingly conducted for specific locations. For example, Kirshen, Ruth, and Anderson (2008) examined the impacts of climate change in the Boston metropolitan area (e.g., temperature changes, sea level rise, river flooding, storm surge) and evaluated adaptation measures in various sectors (e.g., energy, infrastructure, water supply and quality, health). Their analysis highlighted the interdependencies of the various systems and adaptation response strategies and the importance of taking a system-wide approach to adaptation analysis and planning. Significant benefits are suggested compared to the costs of adaptation measures in the Boston area and New England under a range of future climate scenarios (Extreme weather events: The costs of not being prepared, 2014). Other approaches, such as risk assessment and cost-effectiveness analysis, are also being suggested to evaluate state and local adaptation actions (e.g., Center for Climate Strategies, 2011).

Private, risk-based modeling and analytical approaches are also employed by states and cities in climate change adaptation assessments. For instance, Swiss Re's natural catastrophe probabilistic models were used to help understand the potential impacts of wind and storm surge and quantify the costs and benefits of resilience initiatives in New York City (The City of New York, 2013). The limitations noted in the New York City study (The City of New York, 2013) are representative of risk assessments and economic analysis at the state and local levels, that typically not all climate risks are identified and included in an analysis; an analysis does not always reflect future socioeconomic trends when projecting impacts; and analysis usually focuses more on the direct losses that can be readily measured in dollars – namely, damage to assets – without evaluating a broad set of impacts.

3.2 Climate change BCA in selected OECD countries

The use of BCA is widespread for government appraisals undertaken within the United Kingdom. All public sector policies, programs, and projects are required to be appraised using the methodology set out in the "Green Book" (HM Treasury, 2011). This recommends that BCA is used for comparing the merits of different policy options. The underlying principles of this guidance are compatible with good practice for climate change adaptation, although there has yet to be a comprehensive evaluation of the extent to which these principles are reflected in practice. Baselines are set on the best estimate of what is expected to happen in the absence of further policy intervention, rather than extrapolation of previous trends. The discount rate is set at 3.5% per year for the first 30 years and then declines gradually. Non-market goods and services should be valued where possible and distributional impacts made explicit. The main tool used to manage uncertainties is sensitivity analysis, which examines how the costs and benefits of different options would be affected by different values of key, uncertain variables. In principle, this could include uncertainty about the future effects of climate change. Monte Carlo analysis is recommended for areas where a more sophisticated treatment of uncertainty is recommended.

The UK government published the supplementary "Green Book" guidance in 2009 to specifically address climate change adaptation (HM Treasury, 2009). It added two new elements to the decision-making process. First, it provided a screening tool to identify where climate change would be important in the policy appraisal process. The second element was a greater emphasis on the treatment of uncertainty. It recommended that, where appropriate, policy makers use a Real Options Approach for policy appraisal. This approach allows the benefits of flexibility to be valued. It has, however, proved challenging to apply outside of its traditional domain of appraising infrastructure design.

The Mexican Government's General Law on Climate Change, introduced in 2007 (Government of Mexico, 2007), was enacted in 2012. It is supplemented by Mexico's National Climate Change Strategy, which set policy goals for climate change mitigation and adaptation (Government of Mexico, 2012). Its adaptation strategy highlights the use of BCA for prioritizing climate change adaptation measures and has been developed in partnership with the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (GIZ, 2014). The BCA methodology has not yet been fully developed, but pilot studies are being implemented in three sectors: irrigated agriculture, water resource management, and forests protection. The BCA is developed using the best available data and inputs from local experts. Estimated costs and benefits and the assumptions (e.g., discount rate, time horizon, investments, taxes) are required to be stated in a final document, to ensure that the analysis is clear and transparent. If it is deemed infeasible to monetize main categories of costs and benefits, cost-effectiveness analysis and multi-criteria analysis are used as complementary tests to accompany BCA.

4 Discussion and emerging findings

Based on our review of current developments and applications of economic analysis for public sector decision making in general and for climate adaptation more specifically, a set of analytical considerations emerges. First, the complexity of economic analysis and tools needs to be balanced with the practical applicability and the scale of the problem. In some situations, a screening assessment that ranks options based on qualitative assessment may be appropriate and would provide useful information to aid decision making and associated processes. In other cases (e.g., climate risks are high and uncertainties surrounding climate impacts and adaptation costs and benefits are large), multiple tools and approaches may be needed to ensure the analysis is robust and sufficiently captures key uncertainties important for decision making. As discussed in the literature, alternative approaches to BCA can include cost-effectiveness analysis, multi-criteria analysis, expert judgment, and the robust decision-making framework (see UNFCCC, 2011 for further discussion on these various approaches, and Lempert (2014), on robust decision-making frameworks).

Second, the costs and benefits of "hard" measures (e.g., building infrastructure) and measures with clear market impacts (e.g., adoption of drought-resistant crop varieties) are more readily evaluated compared with "soft" measures (e.g., behavioral interventions, policies, and programs) and those measures without clear markets (e.g., ecosystem-based options). As such, "hard" measures can be favored over "soft" measures because of the ability to better quantify their benefits and costs, even though critical "soft" measures tend to be more relevant to facilitate adaptation (OECD, 2008; World Bank, 2010). Economic research and tools are continuously evolving to address some of the more challenging issues, such as the valuation of ecosystem services (e.g., see UK Defra, 2007; U.S. EPA Science Advisory Board, 2009). In addition, empirical methods and techniques, such as quasi-experiments and randomized control trials developed to evaluate effectiveness of policies and programs (e.g., for health care, education, and development and behavioral interventions), can also be applied to inform the costs and benefits of some "soft" adaptation measures. BCA practitioners need to be aware of these potential biases, as well as advances in relevant economic research especially with respect to these "soft" measures and non-market impacts.

Third, transparency of economic analyses that evaluate the costs and benefits of adaptation measures is essential to support decision making. Clearly conveying assumptions, inputs, and methodology can help to build trust in the results of the analysis and supports comparability. Analyzing and disclosing the sensitivity of results against key variables is particularly important given pervasive uncertainties. Similarly, given the wide range of climate change impacts across many locations, developing consistency in BCA practices would facilitate information sharing, including benefits transfer. As a related issue, evaluating different types of adaptation decisions using a consistent framework and metrics allows comparisons of different options and helps ensure economic efficiency of adaptation investments for a given level of expenditure. Methods and tools that are transparent, accessible, and easy to use would provide far greater value than complex ones that are hardly used.

Fourth, defining the boundary of analysis will be important for understanding the societal costs and benefits of adaptation efforts. While BCA has been and likely will be mostly applied to evaluate project-based adaptation measures, there may be important implications for cross-sector and economy-wide effects. For example, the energy-water nexus is emerging as an important research area because of many interdependencies. These interactions can be particularly important for understanding the welfare impacts of a suite of measures, and the synergies and tradeoffs of alternative adaptation strategies on the regional, sectoral, or national level (e.g., water use and competition between the energy and agriculture sectors).

Fifth, uncertainties associated with climate change are a fundamental challenge to economic analysis of the climate change problem and potential responses. Approaches have been developed within the framework of BCA to address uncertainty, such as with the use of scenario analysis, expert surveys, and Monte Carlo analysis (see, e.g., Brent, 2006; Florio, 2014; HM Treasury, 2011; OMB, 2003). These best practices should be applied when performing economic analysis of adaptation measures. Consideration should also be given to integrating other disciplines and complementary economic tools with BCA to address uncertainty. For example, given the complex and uncertain nature of global climate change, there is a widely held view that climate change adaptation activities are best considered in a risk management framework (e.g., IPCC, 2012; Keller, Yohe, & Schlesinger, 2008; Klein et al., 2007; National Research Council, 2010). Farrow (2004) demonstrated that the tools for uncertainty analysis in the risk assessment and risk management paradigm and the "real options" method can be combined with BCA to improve the treatment of uncertainty and irreversibility. More recently, development of robust decision analysis frameworks also helps to address some of the limitations of BCA [see Lempert (2014)].

Finally, BCA is traditionally agnostic to equity considerations. However, distributional concerns are significant in the case of climate impacts, where poor and disadvantaged groups are often more vulnerable to climate change. It is important that the distribution of welfare impacts of climate change and adaptation measures on different groups be included in the analysis, including the sensitivity of those distributions to alternative assumptions and equity weights. As with BCA in general, it is important to be transparent about the distribution, in addition to the net values of costs and benefits.

5 Concluding thoughts

Global adaptation investment needs are estimated to be close to $100 billion per year (World Bank, 2010), and adaptation costs are estimated to be as high as tens to hundreds of billions of dollars in the US by the mid-century (Sussman et al., 2014a). Given the potential scale of adaptation investments, there is need for continued improvement of economic analysis and tools to provide robust information on costs and benefits to support climate change adaptation initiatives and appraise investment decisions at different scales.

Existing economic theory and tools can be applied to address many of the analytical needs in the context of climate change adaptation. The issues of complexity, uncertainty, and long decision time frames are not unique to climate change adaptation, but the combination of these factors poses challenges when undertaking analysis. Moreover, economic analysis of climate change adaptation also needs to address some of the perennial issues with applied BCA, including the definition of baseline (i.e., what autonomous adaptation should be assumed), the incorporation of distributional impacts, the choice of discount rates, and non-market valuation (in particular, valuation of ecosystem services).

Sectors that are sensitive to climate variability or weather events have already developed extensive risk assessment methods and risk management tools to support decision making under uncertainty (e.g., in disaster risk management, coastal management, water resource management, agriculture, and public health sectors). To be effective, adaptation planning for climate change could start from established risk management methods and tools, and evaluate whether existing tools need to be enhanced to include considerations specific to climate change or if the methods need to be improved to address the uncertainty associated with climate change.

To date, applications of BCA exist mostly in the context of project-based appraisal. Evaluation and prioritization of comprehensive adaptation planning at the sectoral, regional, or national level is largely missing. The potential interactions, synergies and tradeoffs, as well as the cross-sector and general equilibrium effects of a suite of adaptation measures, are important to understand. This is an area needing more analysis, especially in the context of sectoral and national adaptation planning.

As observed in the recent IPCC Fifth Assessment Report, "economic analysis of adaptation is moving away from a unique emphasis on efficiency, market solutions, and benefit/cost analysis to include consideration of non-monetary and non-market measures, risks, inequities, behavioral biases, barriers and limits, and consideration of ancillary benefits and costs" (IPCC, 2014a, chapter

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17, p. 2). More than one method may be needed to analyze adaptation choices. Despite the challenges and limitations, there will remain and, as the authors of this paper would argue, ought to be a strong role for economic analysis – in particular BCA – for evaluating and prioritizing adaptation investments and understanding the tradeoffs and potential interactions of different policy decisions.

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