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Accounting for the Effects of Employment, Equity, and Risk Aversion in Cost–Benefit Analysis: An Application to an Adaptation Project

Abstract: This paper sets out to explore to what extent integrating employment effects, equity, and risk aversion within cost–benefit analysis (CBA) affect the economic appraisal of a climate change adaptation project designed to protect against flood risk in a region of Bilbao (Basque Country, Spain). Four CBAs are conducted: (i) a standard CBA; (ii) a standard CBA considering equity; (iii) a standard CBA considering equity and employment; and (iv) a standard CBA considering equity, employment and risk aversion. All CBAs are conducted using a time frame of 2014–2080 and considering a 100-year return period under a middle of the road emission scenario (RCP4.5). A sensitivity analysis is also undertaken. Results suggest that the economic efficiency of the adaptation investment is contingent on what types of considerations are included within CBA. Integrating elements of employment, equity and risk aversion can strengthen or weaken the case for action (leading to higher or lower net-present values) and (depending on the discount rate chosen) may even be the deciding factor for determining whether a particular action should be carried out or not (whether the net-present value is positive or negative).

Keywords: climate change adaptation; equity; risk aversion; employment effects; cost-benefit analysis.

JEL classifications: Q52; Q54; Q56

1. Introduction

Cost–benefit analysis (CBA) is one of the most widely applied tools for assessing the feasibility of private and public investments in climate change adaptation

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(Markanday *et al.,* 2019). Able to compare various measures over time, CBA permits the evaluation of adaptation pathways[1] for reducing vulnerability, enhancing adaptive capacity and building resilience in the face of climate change. CBA works by measuring how efficient an investment is based on its net present value (NPV). If the NPV is positive, it means that the benefits of the investment outweigh its costs, and the investment is considered efficient (although that may not be sufficient for it to be accepted[2]). If the NPV is negative, it means that costs exceed benefits, and the investment is considered inefficient. This sets a monetary basis for justifying why a proposed policy or program should go ahead. CBA calculates the NPV by measuring the change in net benefits, that is benefits (B) minus costs (C), over time (*t*) relative to a no-project scenario when a discount rate is applied[3] (*r*) (see Equation (1)).

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{\mathrm{B} - \mathrm{C}_t}{(1+r)^t} \tag{1}$$

The main attractiveness of CBA lies in its ability to weigh the costs and benefits of a decision, using one common metric – money. Using monetary terms as the sole unit of CBA has been argued to provide an objective assessment of whether public policies or programs will meet citizens' needs (and at the same time fits well within budgetary processes). Assessing the performance of various measures over time can inform policy-makers about the expected success of adaptation programs and help them to allocate resources efficiently. At least on the cost side, the focus on monetary units makes it relatively easy and straightforward for users of CBA, and promotes transparency by requiring decision-makers to reveal all the assumptions and uncertainties underpinning analyses. CBA is often a preferred tool of economists and policy-makers who aim to get the most desirable results from the least amount of available resources.

Despite its advantages, many scientists have expressed concerns over CBA when it comes to valuing public investments with environmental and climate change implications (see e.g., Ackerman & Heinzerling, 2002; Hanley, 1992 for a critical review of CBA when dealing with environmental matters). Among the most contentious points, two particularly pertinent issues arise. The first relates to the measure of environmental and social benefits that are not traded in the market. CBA deals with

1 An adaptation pathway is defined as a strategic, flexible and structured decision-making strategy composed of a sequence of steps or decision-points over time (Haasnoot *et al.,* 2013).

2 A related indicator to NPV is the ratio of the present value of benefits to costs (otherwise known as the benefit–cost ratio or BCR). An NPV > 0 implies a BCR > 1, which can be considered necessary for project approval. When funds are limited governments sometimes ask for a BCR considerably greater than 1, perhaps 2, or even higher.

3 Based on the assumption that society prefers to receive benefits in the short-term, while delaying costs to the future, then a discount rate can be applied to costs and benefits so as to exponentially discount the value of outcomes as they occur further in time. This means that options with more immediate benefits are often favored over those with more long-term benefits.

this by using artificial prices to act as a proxy for non-market values (such as those concerning life, health, and nature). Popular methods for valuing non-market items include approaches such as the contingent valuation method, the avoided-cost approach, the travel-cost approach, and estimating opportunity costs[4]. These methods arouse criticism from researchers who argue that due to the complexity and multifunctional nature of environmental resources, the aggregation of private values is far too simplistic a measure of benefit to human welfare (Kumar & Kumar, 2008). On top of this, methodological differences in valuation approaches make the comparison of common item values across studies difficult. The reliance on artificial prices for non-market values also means that outdated values must be consistently updated to reflect current conditions (i.e., when resources are available to carry out new assessments) or replaced by (at times unsuitable) values transferred from other, supposedly similar, sites. The challenges of including non-market items into CBA means that often-times such values are misrepresented or excluded altogether from assessments. Disregarding critical non-market values in CBA is particularly problematic in the case of climate change adaptation, especially when valuing non-technical solutions (e.g., capacity building or ecosystem-based solutions) with high social or environmental benefits. Failure to capture true costs and benefits in these cases often results in such solutions being ranked lower or afforded less priority than other more verifiable solutions (Watkiss *et al.,* 2015).

The second issue relates to how environmental costs and benefits are discounted over time. The often long-time horizons involved in environmental and climate change decision-making means that many environmental benefits (e.g., afforestation) will only accrue in the distant future – making the choice of discount rate an important factor in cost–benefit assessments (Chiabai *et al.*, 2012). Using high positive rates (e.g., market rates) can trivialize catastrophic events even in the medium term and run the risk of causing irreversible environmental and social harm since little importance is given to damages in the future. As Ackerman and Heinzerling (2002) explain, using a discount rate of 5 % can make the death of a billion people 500 years from now seem less serious than the death of one person today. Different rates such as the market rate, the consumption rate of interest, the adjusted return in the private sector, and the social time preference rate have been proposed (Markanday *et al.,* 2019), but notable environmental economists are calling for near-zero rates (Stern *et al.,* 2006; Dasgupta, 2007; Weitzman, 2009), or declining rates (Cropper & Laibson, 1998; Philibert, 2006; Gollier, 2008; Groom, 2014) to be used instead.

Scientific discourse on environmental CBA has predominantly centered around issues pertaining to non-market valuation and discounting. Less discussed is the ability of CBA to accurately reflect and meet societal needs and states. We will argue

4 For more information see Markandya and Richardson (2017).

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in this paper that there are three (often neglected) dimensions of CBA that require proper attention in the context of decision-making on climate change change adaptation. The first relates to the consideration of employment effects. Investments in adaptation could have direct and induced positive effects on the labor market by; for example, directly creating jobs, facilitating the creation of jobs, or improving labor supply. This is particularly important when considering economies with high levels of unemployment, wherein proposed climate policies or projects could lead to significant societal benefits or costs. CBA has difficulty capturing these employment effects, mainly because it tends to assume distortions in the labor market, such as involuntary unemployment, do not exist (Bartik, 2012; Masur & Posner, 2012). This implies that any additional labor demand generated by investments would have to be met by moving people from other employment. Assuming that the value of foregone work (based on the marginal product of labor) and non-work (based on the subjective value of time) activities are both equal to the market wage, and the cost of project labor is also equal to the market wage, then workers would not gain from additional employment. The cost of project labor would have to be higher than the market wage for workers to derive any benefit from additional employment, which is not normally assumed to be the case. By calculating employment effects in this way, CBA cannot capture any positive effects on labor markets, since any benefits arising from additional employment would be offset by higher labor costs (Bartik, 2012). To address this issue, researchers have adopted various employment models within CBA, the outcomes of which tend to vary with changes in problem-context, research approach, and underlying model assumptions. While these differences lead to variations in benefit estimates across studies, the literature tends to indicate that when involuntary unemployment is high, benefits relating to increased employment also tend to be high (Ray, 1984). Current discourse over the short-, medium-, and long-term impact of climate policy on jobs is complex. The shift from high-carbon to more labor intensive low-carbon activities is expected to lead to job creation in the short term, while medium-term impacts are likely to see an economy-wide ripple effect as jobs are created and lost across affected industries. In the long term, more dynamic employment effects are expected, as innovation and technological development create new opportunities for investment and growth (Fankhauser *et al.,* 2008). The potentially widespread political, economic, and social consequences of climate change decision-making on labor markets has made it an important discussion point for policy-makers. CBA for climate decision-making would benefit from better consideration of employment effects if it wants to ensure a more holistic understanding of the risks and opportunities associated with these structural changes.

Another equally overlooked aspect of CBA from an adaptation decision-making standpoint relates to the equitability of investments (i.e., how benefits and costs are distributed among those affected by the project). CBA deals with effects on well-

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being by parsing monetary equivalents, that is determining the amount individuals are willing to pay (WTP) for policies that benefit them or are willing to accept (WTA) for policies that disadvantage them. By focusing on aggregate benefit, CBA automatically favors policies with a positive sum of monetary equivalents, irrespective of how values are distributed throughout society. This becomes especially problematic when deciding between policies or programs that affect diverse income groups. Since the rich can afford to pay more for policies or programs that they prefer, the poor are almost always at a disadvantage. The bias generated by the efficiency objective is usually justified on the basis that it would ensure available resources yield the maximum increment in total national income and that governments can use fiscal devices to redistribute project-generated revenues in any desired direction (Squire & Van der Tak, 1975). But government capacity may be limited when it comes to redistributing income, especially in developing regions that may lack the necessary administrative and organizational structures for carrying out this objective. Taking into account the distributional consequences of climate-related decision-making is important since such decisions must consider both the spatial distribution of environmental impacts as well as the ensuing distributional consequences of political and social effects caused by those impacts (Murieta *et al.,* 2014). As it stands, climate change has a disproportionately adverse impact on lower-income countries and poor people in high-income countries, calling into question how best to tackle climate and social injustices arising from climate change and the measures taken to address it (Levy & Patz, 2015). Adaptation decisions can achieve "equity in outcome" by recognizing who benefits or suffers from climate impacts or policy decisions (Adger *et al.,* 2005). As it stands, environmental decision-making based on current investment assessment approaches has led to adaptation actions that reinforce existing inequalities and do little to relieve underlying vulnerabilities (Adger *et al.,* 2003). Reactive adaptation in response to extreme climate events, in particular, has been found to exasperate vulnerabilities and reinforce social and economic inequalities (Glantz & Jamieson, 2000). Proper consideration of the distributional consequences of environmental decision-making will be vital for ensuring resilient futures in the face of climate change while also safeguarding fairness and equity objectives within climate change decision-making.

The final problematic area of CBA discussed in this paper concerns how risk preferences are integrated into decision-making. Economics tends to assume that people are both risk-averse and seek to maximize their expected utility. For example, individuals are willing to pay for insurance that limits their loss in the case of an unfavorable event (i.e., their home being flooded). This would mean that being exposed to certain risks represents a cost to risk-averse individuals who are willing to pay to reduce or eliminate their risk altogether. Despite this assumption, risk aversion is typically ignored in CBA, and as Kaufman (2014) explains, there are two potential reasons for this. The first is that the well-established literature on public economics suggests that governments should be risk-neutral (i.e., assume zero risk aversion) when it comes to risky public investments with uncertain costs and benefits, such as adaptation projects. This is justified on the basis that when populations are relatively large, risk premiums for small public investments with uncertain effects converge to zero because they can be “spread out” among members of society. But this rationale does not hold in cases of pre-existing environmental uncertainty. The arguments for risk neutrality are valid for projects with uncertain costs and benefits, but not for projects that reduce pre-existing uncertainty in the absence of environmental policy (commonly referred to as “baseline” or “business-as-usual” uncertainty) as one of their key features. Such environmental policies would provide risk-reducing benefits to all affected risk-averse individuals, and in no sense is the risk “spread out” across all those affected. Policy evaluations should account for risk aversion in situations where pre-existing uncertainty is significant. The second reason for not integrating risk-aversion into CBA stems from the inherent computational and theoretical difficulties involved in quantifying risk aversion, and thus in establishing an acceptable level of societal risk aversion. Assuming that individuals are risk-averse, then standard cost–benefit analysis underestimates benefits (in terms of avoided losses), because household WTP to avoid costs does not include WTP for reduced risk. From a theoretical point of view, this restricts the ability of CBA to adequately assess situations wherein societies might display high levels of risk aversion or to capture risk aversion relative to uneven spatial impacts, such as those caused by climate change. Proper inclusion of benefits related to the avoidance or reduction of climate change risks is likely to be an important determinant of net efficiency gains within CBA.

How to value effects of employment, equity, and risk aversion are three important considerations for CBA practitioners, especially given that policy-makers have been known to rank efficiency below other policy objectives such as equity and political acceptability (Hanley *et al.,* 1990). This paper will explore whether, and if so how much, integrating these aspects can affect the outcome of CBA, using a real adaptation project in Bilbao, Basque Country (Spain) as an example. The next section will describe the methodology used to integrate employment, equity, and risk aversion dimensions into CBA. After which, Section 3 will go on to discuss the main findings, before finishing with concluding remarks in Section 4.

2. Materials and methods

To demonstrate the sensitivity of climate change decision-making to considerations of employment, equity, and risk aversion, this study compares the economic

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efficiency of an adaptation project across four cost–benefit scenarios: (i) a standard CBA (considering capital costs and benefits in terms avoided damages); (ii) a standard CBA including employment effects; (iii) a standard CBA including employment effects and equity; and (iv) a standard CBA including employment effects, equity, and risk aversion. All values, unless otherwise stated, are given in 2015 prices.

2.1 Case study: an adaptation investment in Bilbao, Basque Country (Spain)

The city of Bilbao and its extended metropolitan area is home to over 850,000 people (EUSTAT, 2018). Due to its hilly terrain, steep valleys, high levels of rainfall, and densely urbanized low-lying areas, the city faces a high risk of flooding (Basque Government, 2007). Following a catastrophic flood event that hit the region in 1983, causing 37 deaths and €1.206 billion in economic damages (Olcina *et al.,* 2016), several infrastructure measures were put in place to protect the city from future flood events – but some risk still remains (Figure 1). In 2012, concerns were raised by the

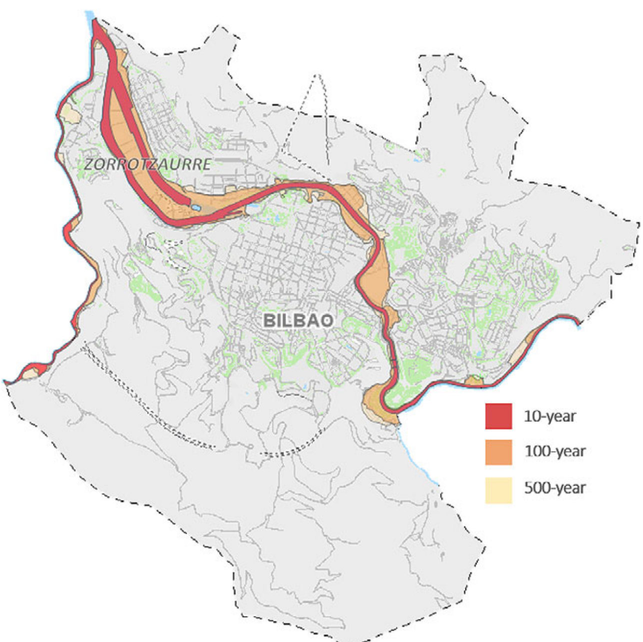

Figure 1 Flood risk in the city of Bilbao from 10-year, 100-year, and 500-year flood events. Source: GeoEuskadi data portal.

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Figure 2 The proposed urban island of Zorrotzaurre.

Basque Water Agency (URA) when plans to build a new urban district on the Zorrotzaure peninsula, an old industrial site at severe risk of flooding, were proposed. In light of this, the city suggested opening and widening the adjoining Deusto canal, turning Zorrotzaure into an island (Figure 2). The proposed measure was designed to improve the drainage capacity of the Bilbao Estuary by opening and widening the width of canal to 75 m, thereby significantly reducing the risk of flooding in the proposed district and neighboring areas further upstream. With an estimated cost to the city of €20.9 million and expectations to reduce the water level by up to 1.43 m in some areas, construction of the project began in 2014[5] (Climate-ADAPT, 2016). By the year 2080, considering a 100-year return period under climate change, the adaptation project is expected to reduce climate change–induced flood damages by between 67.4 % (lower bound estimate) and 65.9 % (upper bound estimate) with avoided damages expected to reach between €289 and €347 million (Basque Government, 2007; Osés-Eraso *et al.,* 2012), with corresponding benefits in the intervening years. These estimates represent lower and upper bounds, calculated as the difference in damages with and without the opening of the Deusto canal (Table 1)[6]. See endnotes for an explanation on how these values were calculated.

5 Zorrotzaurre was officially turned into an island in October 2018. In addition to the opening of the canal the city of Bilbao also plans to construct a flood protection barrier and storm-water tanks to deal with flood risk in the area

6 Climate change damage (and subsequent benefit) estimates used in this paper are derived from two reports. First, damages values for the base scenario, the reference scenario, and the climate change scenario (without the opening of the Deusto canal) were taken from a 2007 Basque Government report on the valuation of climate change costs for the Basque Country (Basque Government, 2007). The report maps physical areas under risk of flooding for the city of Bilbao based on 10-year, 100-year, and 500-year return

Table 1 Expected annual damages for a 100-year flood event for the year 2080.

	Lower bound estimate	Upper bound estimate
Base case	269.04	329.45
Reference case	274.55	336.85
Climate change scenario (without the opening of Duesto Canal)	429.29	526.67
Climate change scenario (with the opening of Duesto Canal)	139.86	179.44
Total Benefits (avoided damages)	289.43	347.23

Damages are given for a base scenario, a reference scenario (considering socio-economic changes), and a climate change scenario (considering an increase in precipitation levels and a 25 % increase in flood risk) for the year 2080.

2.2 CBA scenarios

Scenario I: *Standard CBA.*

Under this scenario, the capital costs of the adaptation solution are considered alongside benefits, measured in terms of avoided damages. Estimated benefits do not take into account the effects of employment, equity, or risk aversion. The project is estimated to cost €20.9 million, distributed in equal annual sums of €5.225 million across the first 4 years while construction was underway (2014–2020). We assume that benefits only started accruing from the year 2018, once construction was complete and the adaptation functional. We estimate an annual benefit, consisting of a reduction in expected damages given a 1:100 year flood. The value stream of these benefits starts in 2018, but as we only have a damage estimate for 2080, it is necessary to work back to an expected damage for 2018 and subsequent years. This is done by considering the economic growth expected to take place in the region between 2018

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periods for the year 2080. Physical impacts were then translated to economic terms based on the different damage categories under risk (i.e., residential and non-residential buildings, buildings of historic and cultural heritage, mortality and morbidity effects, interruptions in transport, emergency services etc.). Damages are given for a base scenario, a reference scenario (considering socio-economic changes), and a climate change scenario (considering an increase in precipitation levels and a 25% increase in flood risk) for the year 2080. Next, the change in damages considering the opening of the Deusto canal were based on flood reduction estimates from a report by Osés-Eraso *et al.* (2012). Using damage probability curves, the study builds on the 2007 report to consider how opening the Duesto canal would affect damage estimates for 10-year, 100-year, and 500-year flood events. The authors estimate that for a 100-year flood, damages, when considering the opening of the Deusto canal, would be reduced by 67.42% (lower bound scenario) and 65.93% (upper bound scenario). These percentages are used to calculate the economic damages under a climate change scenario when the opening of the Deusto canal is considered. All monetary values derived from the initial reports were converted to 2015 prices using the consumer price indices for Spain taken from the OECD databank.

and 2080. Economic growth rates for the European Union under SSP2[7] are applied to the years preceding 2080[8]. These rates correspond to a growth of 2.5 % between 2018 and 2030, 2.01 % between 2031 and 2050, and 1.05 % between 2051 and 2080 (https://doi.org/10.1016/j.gloenvcha.2015.02.012, 2017; Leimbach *et al.,* 2017; Riahi *et al.,* 2017). This gives us an annual benefit value of €109.44 million[9] for the year 2018. Benefits for subsequent years are then adjusted considering a discount rate of 3.5 % and the likelihood of a 100-year flood event occurring in any given year (1 %).

Scenario II: *Standard CBA including employment.*

This scenario considers the same conditions as in scenario I but goes a step further to consider the effect that the adaptation would have on employment in the region. Employment effects within CBA are measured based on the shadow wage rate (SWR), (often synonymous with the social opportunity cost of labor). The SWR refers to the loss of other labor alternatives when one alternative is chosen. That is to say, it measures the difference in welfare (in economic terms) that occurs when reallocating workers from one job to an alternative job in the new project. As it stands, the literature on CBA offers different formulas for deriving the SWR (Lewis, 1954; Dasgupta & Pearce, 1972; Marglin & Sen, 1972; Little & Mirrlees, 1974; Roberts, 1982; Marchand *et al.,* 1984; Drèze & Stern, 1987; Brent, 1991; Cowell & Gardiner, 2000; Johansson-Stenman, 2005) based on different assumptions regarding labor (and sometimes capital and product) market conditions. Generally speaking, the literature on shadow wages tells us that when involuntary unemployment is high, the benefits of additional employment also tend to be high (Ray, 1984). In this study, we use shadow wages derived by Del Bo *et al.* (2011) for the Basque Country. In their study, the authors develop a simple framework based on well-established CBA theory, specifically a combination of the Little and Mirrlees (1974) and Drèze and Stern (1990; 1987) frameworks to empirically compute shadow wages and conversion factors across European regions. Structural characteristics and labor market conditions are derived based on functions such as GDP per capita, short- and long-term unemployment, migration flows, and the role of agriculture in the regional economy. Regions are then grouped into one of four clusters (with differing labor market conditions): (i) fairly socially efficient; (ii) quasi-Keynesian unemployment; (iii) urban labor dualism; and (iv) rural labor dualism. The Basque region is classified as having a fairly socially efficient labor market with a relatively high-income level,

7 SSP stands for Shared Socioeconomic Pathways, which were developed based on different technological, socioeconomic and climate policy trajectories. SSP2 represents a middle of the road socioeconomic scenario.

8 Data (Version 1.0) available at: https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10#pastreleases

9 This is considering the lower bound benefit estimate of €289.43 million for the year 2080.

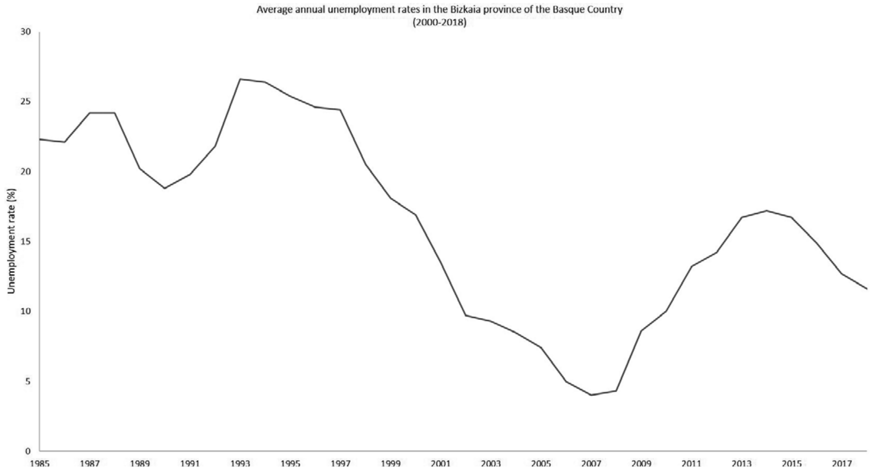

Figure 3 Annual unemployment rates for the Bizkaia province of the Basque Country (1985–2018).

positive net migration, and relatively low unemployment rates. Using the shadow wage rate, the authors estimate conversion factors for each cluster of regions. These can be applied to project costs to adjust for labor market conditions in the region. Del Bo *et al.* (2011) estimate a conversion factor of 0.99 for the Basque Country and regions with similar labor characteristics. It is important to note, however, that the authors use 2007 data for the Basque Country in their analysis, when regional unemployment was its lowest (4 %) in recent history (Figure 3)[10]. Following the 2007–2008 financial crisis, unemployment rates in the Basque Country rose substantially and did not start declining again until 2015. Considering this, we can expect that in reality the conversion factor for the Basque Country would be much lower.

For this reason, we use the regression model and coefficients from Del Bo *et al.* (2011) to adjust for more current employment conditions in Bilbao. Holding all else constant, if we assume the unemployment rate to be 11.6 % (the 2018 rate of unemployment in the province of Bizkaia) then the adjusted conversion factor would be 0.79. We adjust labor costs by applying this estimated conversion factor, which results in a reduction in total costs compared to the previous scenario. For a detatiled step-by-step guide on accounting for employment effects using shadow wages in CBA, see Annex I, Supplementary Information.

Scenario III: *Standard CBA including employment and equity.*

Scenario III adds a second dimension to the CBA, that is, it assesses whether the benefits of the adaptation are equitably distributed among those affected by the

10 Unemployment rates are shown for the Bizkaia province of the Basque Country, where the city of Bilbao is located. Unemployment data are derived from EUSTAT (2018).

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Table 2 Population, income and distributional weights by affected district.

District	Number of people affected	Average income	Distributional weight ($\varepsilon = 1$)	Distributional weight ($\varepsilon = 2$)
Abando	1797	35,944	0.59	0.35
Atxuri	724	16,434	1.29	1.67
Bilbao la Vieja	1560	15,108	1.41	1.98
Bolueta	33	14,943	1.42	2.02
Casco Viejo	6681	24,509	0.87	0.75
Castaños	4370	29,160	0.73	0.53
Ibarrekolanda	0	21,113	1.01	1.01
Indautxu	1	35,702	0.60	0.35
Iturralde	0	19,404	1.09	1.20
La Peña	866	15,117	1.41	1.98
La Ribera	1121	17,334	1.23	1.50
Olabeaga	168	16,783	1.27	1.60
San Francisco	414	13,637	1.56	2.43
San Ignacio	863	18,853	1.13	1.27
San Pedro de Deusto	2237	23,759	0.89	0.80
Solokoetxe	267	18,304	1.16	1.35
Zorrotza	320	15,431	1.38	1.90
Total	21,422	21,245 (average)		

project. Monetary equivalents (of benefits) are adjusted by applying different distributional weights to reflect the relative incomes of those people receiving the benefits or bearing the costs of an investment. In this way, lower-income individuals are assigned greater weights to increase their relative importance within decision-making. This method for dealing with equity dates back to the 1960s when Weisbrod (1968) started arguing the relevance of distributional impacts to policy-makers. While at the time, it was included in cost–benefit manuals (e.g., Squire & Van der Tak, 1975) its inclusion in CBA diminished by the 1990s when concerns about income distribution declined. Discussions on the application of CBA in climate change contexts, however, have sparked new interest in the ability of distributional weights to account for some of the intrinsic shortfalls of environmental CBA, that is moral concerns related to economic valuation and the aggregation of costs and damages in rich and poor countries (Kind *et al.*, 2017; Kolstad *et al.*, 2014; Fankhauser *et al.*, 1997; Schmidt *et al.*, 2013; Stanton *et al.*, 2011).

In this study, we used the social welfare function derived from Atkinson (1970) to estimate distributional weights for different neighborhoods with different income bands (Table 2).

The elasticity of social marginal utility of income (ε) reflects the curvature of the utility function, and can vary according to factors such as context, culture, and period

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(Kind *et al.*, 2017). We used two elasticities, of 1 and 2, based on typically proposed rates (Atkinson, 1970; Stern, 1977; Young, 1990; Gouveia & Strauss, 1994; Lambert *et al.,* 2003). This parameter measures the aversion to inequality in social welfare: the higher the value of the elasticity, the more averse is society assumed to be to inequality in incomes when determining social welfare. Overall the evidence suggests that an elasticity close to one. With that value, the social marginal utility of one additional Euro for someone earning €1000 is worth double that of someone earning €2000 (see Annex II, Table 5, Supplementary Information; HM Treasury, 2003). In general, we can expect higher elasticities to make a bigger adjustment for differences in the social marginal utility of income.

A conversion factor based on the ratio between the total expected weighted benefits and the total expected unweighted benefits was then used to adjust benefit values for each year in order to account for distributional effects. In this study, conversion factors of 0.952 (considering an elasticity of 1) and 0.973 (considering an elasticity of 2) have been estimated. Taking the year 2018 as an example, the *weighted* benefits adjusting for equity would be €1.04 million (with an elasticity of 1) and €1.07 million (with an elasticity of 2) compared to €1.09 million (*unweighted*). In this scenario, while costs would remain unchanged, the benefits of the project would decrease compared to scenario II. A detailed step-by-step guide on how to account for equity dimensions in CBA using distributional weights is provided in Annex II, Supplementary Information.

Scenario IV: *Standard CBA including employment, equity and risk aversion.*

Under scenario IV, all three dimensions of employment, equity, and risk aversion are considered on top of the standard CBA. The added-value of adaptation for a risk-averse society is accounted for by estimating the value of a "certainty effect," that is, the added benefit of reducing external (environmental) uncertainty (for risk-averse individuals) by investing in protection. This approach follows the assumption that, even when expected values are the same, risk-averse individuals prefer certainty (e.g., receiving €10) over uncertainty (e.g., 50 % chance of receiving €0 and 50 % chance of receiving €20). Based on this, true WTP for reducing a risk or eliminating it completely would be equivalent to the expected damage (or reduction in the expected damage) plus a risk premium (or reduction in the risk premium). By estimating this certainty effect, we can generate a risk factor for each year based on the ratio between the expected cost of a flood event for a risk-averse versus a risk-neutral society.

Taking the year 2018 as an example, the risk-adjusted cost per person of the event accounting for the certainty effect is estimated to be €58.09[11] and the expected

11 This is the expected loss per person in 2018 (€50.88) plus risk premium, which is measured as the expected utility in money terms with the risk removed (€21,194) minus average actual income Y^* (€21,187).

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loss per person is €50.88 (estimated as loss per person times the probability of the event). The risk coefficient for this year would then be ($\frac{58.09}{50.88}$) and the adjusted benefits in 2018 accounting for risk aversion would be €1,244,307 instead of €1,090,000. This coefficient is calculated for each year and used to adjust expected benefits in subsequent years to demonstrate how the willingness of households to pay to avoid the event, including the WTP of risk averse individuals to reduce or avoid the risk completely might change when risk aversion is included in the analysis. This method for dealing with risk is based on the assumption that households at risk of flooding have not already taken out private insurance to limit their losses in the case of a flood event. We did not have such information available to us when conducting this analysis. If such data were available, then damage costs could be replaced by the sum of insurance payments plus expected uncovered damages. In such cases, a lower coefficient for risk aversion could apply. For a detailed step-by-step guide on how to account for risk aversion in CBA using the certainty effect, see Annex III, Supplementary Information.

We are aware of arguments that individuals do not act as rationally as such an approach to the treatment of risk would require. While this is undoubtedly true, it does not mean that societies should not act using such a rational approach. There remains, however, some doubt as to its suitability for such public decisions. While there are many ways of analysing risk in decision-making (Reeder & Ranger, 2011; Kahneman & Tversky, 2013; Ranger *et al.*, 2013), they do not fit into a CBA framework such as this. One alternative that could be applied is to estimate the risk premium using modern methods of choice experiments, where a selected sample of diverse individuals from the region are presented with a number of options, including the one with the present project design and one with the status quo and asked to choose one. The experiment can also include other project designs that reduce the risk differently to expand the choice set. In each case, a payment is attached to each option (reflecting a possible tax to pay for the project). From the analysis of the results of such an experiment, it is possible to estimate the risk premium that the current population attaches to the project. Of course we cannot do this for future periods as they are not present, but we can make some assumptions on how the premiums would evolve over time. For the use for choice experiments in the context of decisions involving risk see (OECD, 2018).

3. Results and discussion

The results of the CBA of the adaptation investment for the different scenarios are shown in Table 3. A negative NPV indicates that the costs of the project exceed its projected benefits, which means that the project results in a net loss and should not be

Table 3 Total present-value of costs, benefits, NPV, BCR, and IRR of the adaptation investment for 2016–2080 using a discount rate of 3.5 %. Values are in EUR millions.

Scenario	Costs	Benefits	NPV	BCR	IRR (%)
I	19.19	37.89	18.70	1.97	6.51
II	17.59	37.89	20.30	2.15	6.98
$III_{\varepsilon=1}$	17.59	36.06	18.47	2.05	6.71
IV	17.59	45.98	28.40	2.61	7.82

Abbreviations: BCR, benefit–cost ratio; IRR, internal rate of return; NPV, net present value.

implemented. Equally, an internal rate of return (IRR)[12] below the discount rate (in this case 3.5 %) means that the project should not be carried out.

The results show that there are slight changes to the benefit–cost ratio (BCR) depending on the scenario considered. The base case scenario (I), which considers a simplistic assessment of costs (direct investment) and benefits (avoided damages), results in the lowest BCR of 1.97. If a discount rate anywhere above the IRR (6.5 %) is used, then the project would yield a negative NPV and the project would be considered inefficient. If the CBA was to consider the additional employment generated by the project (given labor market conditions and unemployment in the region) (scenario II), then the present value of project costs would fall from €19.19 million to €17.58 million, and the BCR of the adaptation would increase to 2.15. This is based on the premise that there are some workers in the region that are involuntarily unemployed, and those workers would not need added incentive in the form of higher wages to work on the project. The "benefit" of generating employment offsets the additional labor costs associated with incentivising those project workers. The extent of how much costs are reduced would depend on the extent of involuntary unemployment in the region. Generally speaking, we can expect that *ceteris paribus,* the greater the involuntary unemployment in the region, the greater the benefit associated with increased employment.

If we move one step further and consider how benefits are distributed among affected groups (scenario III), we observe that while costs stay the same, the present value of benefits would decrease by €1.83 million (from €37.89 million to €36.06 million). The reduction in benefits for this scenario is due to the fact that the implementation of the project would be most beneficial to individuals with incomes higher than the average wage for Bilbao. Indeed, while only five of the affected neighborhoods have incomes higher than the average of Bilbao, these districts are home to around 70 % of beneficiaries (Table 2). Since benefits are not equitably distributed among affected groups, the adaptation is considered less efficient as a result. In this case, investors might

12 The IRR can be defined as the interest rate at which the NPV of cash flows from an investment is equal to zero.

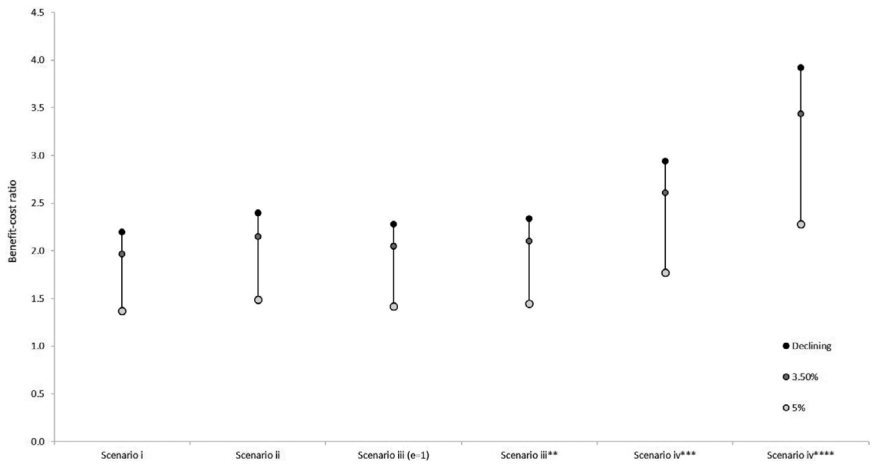

Figure 4 Sensitivity to discount rates (all scenarios), elasticity of income (scenario III), and extent of relative risk aversion (scenario IV). *$\varepsilon = 1$, **$\varepsilon = 2$, ***$\eta = 1$, **** $\eta = 2$.

Table 4 Sensitivity of scenario III when considering high versus low affected income bands ($r = 3.5$ %).

	$\varepsilon = 1$	$\varepsilon = 2$
Unadjusted	2.05	2.10
Lowest affected income band[a]	3.36	5.23
Highest affected income band[a]	1.27	0.75

[a] Refer to Appendix I for a breakdown of beneficiaries and income groups affected by the adaptation project.

consider allocating funds to projects that are deemed more socially (or economically) desirable. Given the types of income groups considered, the BCR is not very sensitive to a change in the elasticity of income from 1 to 2 (Figure 4).

It is important to acknowledge here the growing evidence-base that highlights the disproportionate impact that climate change has on poor and marginalized groups. This means that for many adaptations the consideration of equity within CBA would increase, rather than decrease, the expected benefits of protection. To illustrate this point, we assess how sensitive the BCR would be to changes in income under scenario III. Holding all else constant, if we set the wage of every affected person to that of the lowest affected income group,[13] then the BCR would increase from 2.05 to 3.36 (considering an elasticity of 1) (Table 4). In contrast, when we

13 In this case, the San Francisco neighborhood in Bilbao represents the lowest affected income group, with an average wage in this area of €13,637 (Table 2).

consider the highest affected income band[14] the BCR would drop to 1.27. This test demonstrates that considering the types of income groups targeted by adaptation projects can be transparently integrated within CBA, and can either strengthen or weaken the case for action.

The biggest effect on the BCR comes from scenario IV, which considers all three dimensions of employment, equity, and risk aversion. In this scenario, we include the assumption that societies are risk-averse and therefore, we can expect them to place a higher value on protection than a risk-neutral society otherwise would. Including this value, which is essentially the difference in the expected utility of individuals that are risk-averse versus risk-neutral under a state of protection, raises the overall benefit of the adaptation to €45.98 million, resulting in a BCR of 2.61, and an IRR of 7.82 %. The BCR is highly sensitive to changes in risk aversion when changing the value of η from 1 to 2, the BCR of the project increases to 3.44 (Figure 4). Hence, the more risk-averse society is, the greater the value placed on protection. This finding demonstrates that considering the risk aversion of society can be a very important supporting factor in CBA when making a case for climate change adaptation.

A sensitivity analysis was also conducted to test how variable the BCR is with respect to the discount rate. A discount rate of 5 % and a declining discount rate based on the HM Treasury Green Book guidelines (HM Treasury, 2018) were compared to the base discount rate of 3.5 % (Figure 4). The findings show us that the BCR is highly sensitive to changes in the discount rate across all scenarios, and in most cases (scenario's I, II, and III) a discount rate above 7 % would result in a negative NPV, wherein the project would be considered inefficient (Table 3). Since all costs are distributed within the first 4 years of the project, the sensitivity to the discount rate is mostly contingent on the long-term benefits generated by the adaptation. Choosing the right discount rate in this context is of utmost importance for ensuring that the true value of the project is appropriately recognized. On top of this, the discount rate will also play a decisive role in policy development when deciding between long-term and short-term measures.

4 Conclusion

The long term sustainability of policies and measures when it comes to climate change will be of crucial importance to decision-makers since actions are likely to affect (often interconnected) economic, social, and environmental systems. CBA can be an important tool in this regard. Not only does it have the capacity to test the

14 In this case, the Abando neighborhood in Bilbao represents the highest affected income group, with an average wage in this area of €35,944 (Table 2).

economic profitability of a measure or a set of measures over time, but CBA can also help to rank measures in accordance with other local development and social policy objectives. As demonstrated in this paper, accounting for aspects such as employment, equity, and risk aversion within CBA can help to provide a more holistic perspective on the long-term success of adaptations. Certainly, the efficiency of prospective adaptation investments is contingent on whether these aspects are considered within CBA. Our analysis has shown that introducing employment, equity, and risk aversion extensions to CBA can have important implications for decision-makers who must allocate resources effectively and according to various economic, environmental, and social objectives. Introducing these dimensions into CBA can both strengthen or weaken the case for action, and facilitate more robust and transparent decision processes when deciding between actions, reducing the risk of maladaptation in the future. Future research should explore these important extensions of CBA further, especially in the context of climate change, and in various political, environmental, and social settings, where choosing the right action may avoid potentially catastrophic and irreversible consequences in the future.

Supplementary Materials

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/bca.2020.32.

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References

Ackerman, Frank and Lisa Heinzerling. 2002. "Pricing the Priceless: Cost-Benefit Analysis of Environmental Protection." *University of Pennsylvania Law Review*, 150(5): 1553. https://doi.org/10.2307/3312947.

Adger, W., Neil, Nigel W., Arnell, and Emma L. Tompkins. 2005. "Successful Adaptation to Climate Change across Scales." *Global Environmental Change*, 15(2): 77–86.

Adger, W., Neil, Saleemul Huq, Katrina Brown, Declan Conway, and Mike Hulme. 2003. “Adaptation to Climate Change in the Developing World.” *Progress in Development Studies*, 3(3): 179–195.

Atkinson, Anthony B. 1970. “On the Measurement of Inequality.” *Journal of Economic Theory*, 2(3): 244–263.

Bartik, Timothy J. 2012. “Including Jobs in Benefit-Cost Analysis” *Annual Review of Resource Economics*, 4: 55–73.

Basque Government. 2007. *Metodología Para Valorar Los Costes de Los Impactos Del Cambio Climático En El País Vasco. El Caso de Bilbao – Methodology to Value the Costs of Climate Change Impacts in the Basque Country. The Case of Bilbao*. Bilbao, Spain: Basque Government.

Brent, R.J. 1991. “The Shadow Wage Rate and the Numbers Effect.” *Public Finance*, 46: 186–197.

Chiabai, A., Galarraga, I., Markandya, A., & Pascual, U. (2012). The Equivalency Principle for Discounting the Value of Natural Assets: An Application to an Investment Project in the Basque Coast. *Environmental and Resource Economics*, 56(4), 535–550. doi: 10.1007/s10640-012-9589-8

Climate-ADAPT. 2016. “Public-Private Partnership for a New Flood Proof District in Bilbao.” European Climate Adaptation Platform. https://climate-adapt.eea.europa.eu/metadata/case-studies/public-private-partnership-for-a-new-flood-proof-district-in-bilbao.

Cowell, F.A. and K. Gardiner. 2000. *Welfare Weights*. London, UK: Office of Fair Trading.

Crespo Cuaresma, Jesús. 2017. “Income Projections for Climate Change Research: A Framework Based on Human Capital Dynamics.” *Global Environmental Change*, 42: 226–36. https://doi.org/10.1016/j.gloenvcha.2015.02.012

Cropper, Maureen L. and David I. Laibson. 1998. *The Implications of Hyperbolic Discounting for Project Evaluation*. Washington, DC: World Bank Publications.

Dasgupta, Ajit Kumar and David William Pearce. 1972. *Cost-Benefit Analysis: Theory and Practice*. London, UK: Macmillan International Higher Education.

Dasgupta, Partha. 2007. “The Stern Review’s Economics of Climate Change.” *National Institute Economic Review*, 199(1): 4–7.

Bo, Del, Carlo Fiorio Chiara, and Massimo Florio. 2011. “Shadow Wages for the EU Regions.” *Fiscal Studies*, 32(1): 109–143.

Drèze, J. and N. Stern. 1987. “The Theory of Cost-Benefit Analysis.” In Auerbach, A. and M. Feldstein (Eds) *Handbook of Public Economics* (Vol. II). Amsterdam, The Netherlands: Elsevier North Holland.

Drèze, Jean and Nicholas Stern. 1990. “Policy Reform, Shadow Prices, and Market Prices.” *Journal of Public Economics*, 42(1): 1–45.

EUSTAT. 2018. “Activity, Occupation, and Employment Rate of the Population Aged 16 and over of the Basque Country by Province, Sex and Quarter (%).” Instituto Vasco de Estadistica Data Bank. http://en.eustat.eus/bankupx/pxweb/en/english/-/PX_2307_tab01.px#axzz64PLRwl8X (accessed July 23, 2020).

Fankhauser, S., Tol, R. S., & Pearce, D. W. (1997). The aggregation of climate change damages: a welfare theoretic approach. *Environmental and Resource Economics*, 10 (3), 249–266.

Fankhauser, Samuel, Friedel Sehlleier, and Nicholas Stern. 2008. “Climate Change, Innovation and Jobs.” *Climate Policy*, 8(4): 421–429. https://doi.org/10.3763/cpol.2008.0513

Glantz, Michael and Dale Jamieson. 2000. "Societal Response to Hurricane Mitch and Intra- versus Intergenerational Equity Issues: Whose Norms Should Apply?" *Risk Analysis*, 20 (6): 869–82.

Gollier, Christian. 2008. "Discounting with Fat-Tailed Economic Growth." *Journal of Risk and Uncertainty*, 37(2–3): 171–186.

Gouveia, Miguel and Robert P. Strauss. 1994. "Effective Federal Individual Income Tax Functions: An Exploratory Empirical Analysis." *National Tax Journal*, 47(2): 317–39.

Groom, B. 2014. "Discounting." *Routledge Handbook of the Economics of Climate Change Adaptation, Routledge International Handbooks*: 138–168. Oxon, UK and New York, NY: Routledge.

Haasnoot, Marjolijn, Jan H. Kwakkel, Warren E. Walker, and Judith ter Maat. 2013. "Dynamic Adaptive Policy Pathways: A Method for Crafting Robust Decisions for a Deeply Uncertain World." *Global Environmental Change*, 23(2): 485–498.

Hanley, Nick. 1992. "Are There Environmental Limits to Cost Benefit Analysis?" *Environmental and Resource Economics*, 2(1): 33–59.

Hanley, Nick, S. Hallett, and I. Moffatt. 1990. "Research Policy and Review 33. Why Is More Notice Not Taken of Economists' Prescriptions for the Control of Pollution?" *Environment and Planning A*, 22(11): 1421–1439.

Johansson-Stenman, Olof. 2005. "Distributional Weights in Cost-Benefit Analysis—Should We Forget about Them?" *Land Economics*, 81(3): 337–352.

Kahneman, Daniel and Amos Tversky. 2013. "Prospect Theory: An Analysis of Decision under Risk." In *Handbook of the Fundamentals of Financial Decision Making: Part I*: 99–127. Singapore: World Scientific.

Kaufman, Noah. 2014. "Why Is Risk Aversion Unaccounted for in Environmental Policy Evaluations?" *Climatic Change*, 125(2): 127–135.

Kind, J., Wouter Botzen, W. J., & Aerts, J. C. (2017). Accounting for risk aversion, income distribution and social welfare in cost-benefit analysis for flood risk management. *Wiley Interdisciplinary Reviews: Climate Change*, 8(2), e446.

Kolstad C, Urama K, Broome J, Bruvoll A, CariñoOlvera M, et al. (2014). Social, economic and ethical concepts and methods. In: Edenhofer O, Pichs-Madruga R,Sokona Y, Farahani E, Kadner S, et al., eds. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press; 207–282.

Kumar, Manasi and Pushpam Kumar. 2008. "Valuation of the Ecosystem Services: A Psycho-Cultural Perspective." *Ecological Economics*, 64(4): 808–819.

Lambert, Peter J., Daniel L. Millimet, and Daniel Slottje. 2003. "Inequality Aversion and the Natural Rate of Subjective Inequality." *Journal of Public Economics*, 87(5–6): 1061–1090.

Leimbach, Marian, Elmar Kriegler, Niklas Roming, and Jana Schwanitz. 2017. "Future Growth Patterns of World Regions – A GDP Scenario Approach." *Global Environmental Change*, 42: 215–225. https://doi.org/10.1016/j.gloenvcha.2015.02.005

Levy, Barry S. and Jonathan A. Patz. 2015. "Climate Change, Human Rights, and Social Justice." *Annals of Global Health*, 81(3): 310–322.

Lewis, W.A. 1954. "Economic Development with Unlimited Supplies of Labour." *The Manchester School*, 22: 139–191.

Little, I.M.D. and J. Mirrlees. 1974. *Project Appraisal and Planning for Developing Countries*. London, UK: Heinemann.

Marchand, M., J. Mintz, and P. Pestieau. 1984. “Shadow Pricing of Labour and Capital in an Economy with Unemployed Labour.” *European Economic Review*, 25: 239–252.

Marglin, Stephen A. and Amartya Sen. 1972. *Guidelines for Project Evaluation*. New York, NY: United Nations Industrial Development Organization.

Markanday, Ambika, Ibon Galarraga, Aline Chiabai, Elisa Sainz de Murieta, Bosco Lliso, and Anil Markandya. 2019. “Determining Discount Rates for the Evaluation of Natural Assets in Land-Use Planning: An Application of the Equivalency Principle.” *Journal of Cleaner Production*, 230: 672–684.

Markanday, Ambika, Ibon Galarraga, and Anil Markandya. 2019. “A Critical Review of Cost-Benefit Analysis for Climate Change Adaptation in Cities.” *Climate Change Economics*, 10(4): 1950014. https://doi.org/10.1142/S2010007819500143

Markandya, Anil and Julie Richardson (Eds). 2017. *The Earthscan Reader in Environmental Economics*. Abingdon, UK: Routledge.

Masur, Jonathan S. and Eric A. Posner. 2012. “Regulation, Unemployment, and Cost-Benefit Analysis.” *Virginia Law Review*, 98: 579.

OECD. 2018. *Cost-Benefit Analysis and the Environment: Further Developments and Policy Use*. Paris, France: OECD Publishing.

Olcina, Jorge, David Sauri, Maria Hernández, and Anna Ribas. 2016. “Flood Policy in Spain: A Review for the Period 1983-2013.” *Disaster Prevention and Management: An International Journal* 25(1): 41–58. https://doi.org/10.1108/DPM-05-2015-0108

Osés-Eraso, N., S. Foudi, and I. Galarraga. 2012. “Análisis Del Impacto Socio Económico Del Daño Por Inundación En La Ría de Nervión: Un Cambio de Escenario Ante La Apertura Del Canal de Duesto.” In: *Informe de Avance Del Proyecto*. Bilbao, Spain: Basque Centre for Climate change.

Philibert Cédric (2006) Discounting the future. In: Pannell DJ, Schilizzi SGM (eds) *Economics and the future*. Edward Elgar, Cheltenham

Ranger, Nicola, Tim Reeder, and Jason Lowe. 2013. “Addressing ‘Deep’ Uncertainty over Long-Term Climate in Major Infrastructure Projects: Four Innovations of the Thames Estuary 2100 Project.” *EURO Journal on Decision Processes*, 1(3–4): 233–262.

Ray, Anandarup. 1984. *Cost-Benefit Analysis: Issues and Methodologies*. Washington, DC: The World Bank.

Reeder, Tim and Nicola Ranger. 2011. How Do You Adapt in an Uncertain World?: Lessons from the Thames Estuary 2100 Project. Washington, DC. Available at http://www.worldresourcesreport.org (accessed July 20, 2019).

Riahi, Keywan, Detlef P. van Vuuren, Elmar Kriegler, Jae Edmonds, Brian C. O’Neill, Shinichiro Fujimori, Nico Bauer, et al. 2017. “The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview.” *Global Environmental Change*, 42: 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009.

Roberts, K. 1982. “Desirable Fiscal Policies under Keynesian Unemployment.” *Oxford Economic Papers*, 34: 1–22.

Sainz de Murieta, Elisa, Ibon Galarraga, and Anil Markandya. 2014. “An Introduction to the Economics of Climate Change.” In Anil Markandya, Ibon Galarraga, and Elisa Sainz de Murieta (Eds), *Routledge Handbook of the Economics of Climate Change Adaptation*: 3–26. New York, NY: Routledge.

Schmidt, M. G., Held, H., Kriegler, E., & Lorenz, A. (2013). Climate policy under uncertain and heterogeneous climate damages. *Environmental and Resource Economics*, 54(1), 79–99.

Stanton, E. A. (2011). Negishi welfare weights in integrated assessment models: the mathematics of global inequality. *Climatic Change*, 107(3–4), 417–432.

Squire, Lyn and Herman G. Van der Tak. 1975. *Economic Analysis of Projects*. Washington, DC: World Bank Publications.

Stern, Nicholas. 1977. "Welfare Weights and the Elasticity of the Marginal Valuation of Income." In M. Artis and R. Nobay (Eds), *Studies in Modern Economic Analysis*. Oxford, UK: Basil Blackwell.

Stern, Nicholas, Siobhan Peters, Vicki Bakhshi, Alex Bowen, Catherine Cameron, Sebastian Catovsky, Diane Crane, Sophie Cruickshank, Simon Dietz, and Nicola Edmonson. 2006. *Stern Review: The Economics of Climate Change* (Vol. 30). London, UK: HM Treasury.

Her Majesty's Treasury. 2003. *The Green Book: Appraisal and Evaluation in Central Government*. London, UK: HM Treasury.

Her Majesty's Treasury. 2018. *The Green Book: Central Government Guidance on Appraisal and Evaluation*. London, UK: HM Treasury.

Watkiss, Paul, Alistair Hunt, William Blyth, and Jillian Dyszynski. 2015. "The Use of New Economic Decision Support Tools for Adaptation Assessment: A Review of Methods and Applications, towards Guidance on Applicability." *Climatic Change*, 132(3): 401–416.

Weisbrod, Burton A. 1968. "Income Redistribution Effects and Benefit-Cost Analysis." In *Problems in Public Expenditure Analysis*. Washington, DC: The Brookings Institution.

Weitzman, Martin L. 2009. "On Modeling and Interpreting the Economics of Catastrophic Climate Change." *The Review of Economics and Statistics* 91(1): 1–19.

Young, H. Peyton. 1990. "Progressive Taxation and Equal Sacrifice." *The American Economic Review*, 80(1): 253–266.