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The economics of climate change adaptation and decision-making in cities: Barriers and opportunities across scales

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Year: 2020

Summary

Climate change is likely to have a significant impact on cities worldwide. However, various economic and behavioural uncertainties underlying adaptation decision-making in cities have led to investments in climate risk reduction that are far from optimal. Relatedly, in many cases adaptation measures do little to relieve pre-existing social and economic vulnerabilities, and in some cases can even exasperate them. The challenges of devising effective adaptation responses have exposed various limitations related to the use of traditional economic tools and approaches for supporting decision-making within climate change contexts. Tools such as cost-benefit analysis are frequently used for adaptation despite often neglecting crucial aspects to do with decision-making, such as distributional and non-market effects, intergenerational preferences, risks and uncertainties. Moreover, there is an underlying assumption that adaptation decisions will be shaped predominantly by notions of profit maximisation and so-called rational decision-making, despite a growing and convincing body of evidence from behavioural and experimental economics, which suggests that decision-making under risk and uncertainty is likely to be more complex than this. Over the course of five chapters this thesis will explore some of the critical questions surrounding the economics of climate change adaptation and decision-making, with a special focus on cities and similar urban settings. Chapter 2 first explores the evidence-base related to cost-benefit assessments of adaptation measures in cities worldwide and focuses on how cost-benefit analysis is being used as a decision-support tool in this context. Given the growing stresses posed to natural lands by climate change and ongoing urbanisation, Chapter 3 examines the viability of a new economic approach that can be easily integrated within cost-benefit analysis for promoting natural land conservation in land-use planning decisions across different regions in Europe. Chapter 4 explores three often neglected aspects of cost-benefit analysis of adaptation, related to employment, equity and risk-aversion, and through a case study at the city-level, examines how the inclusion of these values affects decision-outcomes. The final two chapters look further into the growing body of behavioural and experimental research on decision-making under risk and uncertainty. Two economic lab experiments are used to test emerging theories in an adaptation context at the town-level. Specifically, they examine how different risk communication framings and experience with climate change can affect individual levels of risk acceptability and adaptation investment behaviour.

Resumen Extendido

El cambio climático tendrá un impacto significativo en las ciudades de todo el mundo. No obstante, la presencia de incertidumbre en la toma de decisiones de adaptación ha conllevado, en algunas ocasiones, la adopción de estrategias climáticas inadecuadas. En muchos casos, las medidas de adaptación en ciudades son insuficientes en cuanto al alivio de las vulnerabilidades sociales y económicas existentes. En algunos casos incluso, llegan a exacerbarlas. La dificultad asociada al diseño de respuestas efectivas de adaptación ha puesto de manifiesto que las herramientas y los enfoques económicos tradicionales pueden ser inadecuados para apoyar la toma de este tipo de decisiones. Herramientas como el análisis de coste-beneficio (CBA) se utilizan con frecuencia para evaluar la viabilidad de medidas de adaptación, pero a menudo descuidan aspectos importantes, como los efectos distributivos y efectos fuera de los mercados, las preferencias intergeneracionales, los riesgos y/o las incertidumbres. Además, dichos enfoques tienden a suponer que las decisiones de adaptación se diseñan y adoptan bajo los criterios de maximización de ganancias y la toma de decisiones racionales. Sin embargo, las crecientes y convincentes evidencias de la economía del comportamiento y experimental sugieren que la toma de decisiones en materia de adaptación al cambio climático es probablemente, más compleja. En el transcurso de cinco capítulos, esta tesis explora algunas de las preguntas críticas que rodean la economía de la adaptación al cambio climático y la toma de decisiones en ciudades y otros entornos urbanos.

Capítulo 2: Evaluaciones coste-beneficio de la adaptación

Ayudar a las ciudades a planificar medidas de adaptación, requerirá tanto de una evaluación detallada de los impactos del cambio climático en sus diferentes sectores y grupos sociales, como de una evaluación de los costes y de los beneficios de las distintas medidas que se proponen a nivel local. Sin embargo, existe un importante vacío en la investigación sobre el uso del CBA para evaluar medidas de adaptación a nivel local; y además, pese a su uso frecuente como herramienta de evaluación en la viabilidad de dichas medidas, no parece existir estudios que exploren su aplicación práctica.

Realizar un análisis crítico y comparativo del CBA en el contexto de adaptación es importante por, al menos, dos razones. En primer lugar, porque la adaptación considerada económicamente eficiente va mucho más allá de una simple comparación de costes y beneficios. Por ejemplo, debería incluirse aspectos relacionados con la distribución de costes y beneficios, con los costes y beneficios de bienes y servicios no expresados en valores de mercado y con el momento en el que se implementan acciones de adaptación. La consideración inadecuada de este tipo de elementos puede concurrir en la subestimación del coste y de los beneficios de adaptación. Mejorar estas estimaciones ayudará, además, a evaluar el coste total del cambio climático, el cual está compuesto por tres componentes interdependientes: el coste de adaptación, el coste de mitigación y el coste residual del cambio climático. En segundo lugar, porque puede ayudar a proporcionar orientaciones de carácter normativo sobre la eficiencia en la combinación de políticas climáticas, ayudando a los tomadores de decisiones a asignar de manera eficiente recursos entre distintas medidas de adaptación, así como entre medidas de adaptación y mitigación.

El capítulo 2 de esta tesis revisa estudios previos donde se ha aplicado el CBA a medidas de adaptación urbanas, e investiga qué tan factible es el uso del CBA como herramienta de apoyo en decisiones de adaptación. El capítulo aborda la siguiente pregunta:

RQ1: ¿Cuán precisa es la información obtenida en con el uso del CBA aplicado a medidas de adaptación? y ¿constituye esta información una base creíble para los planes de adaptación y para las decisiones de inversión en este campo?

Capítulo 3: Tasas de descuento para promover la conservación del entorno natural

El cambio climático amenaza de forma significativa las especies y los ecosistemas de todo el mundo. La destrucción de hábitats, la alteración de procesos ecológicos clave, la propagación de especies invasoras y nocivas, y la aparición de nuevos patógenos y enfermedades, representan sólo algunas de las principales amenazas a la biodiversidad y a los ecosistemas causados por el cambio climático. La urbanización en curso, es decir, la expansión y el crecimiento de ciudades, intensifica aún más estas amenazas, puesto que genera conversiones a gran escala de paisajes rurales a urbanos. A la luz de esta situación, se han propuesto estrategias de adaptación que apoyen la disminución de los impactos del cambio climático y del desarrollo urbano en el entorno natural. En particular, se han propuesto soluciones basadas en la naturaleza que conservan el estado natural de los ecosistemas y minimizan el impacto humano. Ejemplos de ello son el establecimiento de zonas de amortiguamiento del hábitat (restauración o protección de áreas adyacentes a los hábitats actuales), corredores verdes silvestres, restauración de hábitats degradados, o expansión de áreas protegidas.

A pesar de los considerables beneficios asociados a la conservación del entorno natural, se sigue sucediendo su disminución junto con la desaparición de ecosistemas de todo el mundo. Ahora más que nunca, existe la urgente necesidad de desarrollar mecanismos que consideren de forma adecuada los diversos valores que ofrece la naturaleza para la toma de decisiones en materia de gestión del territorio. A lo largo de los años, las herramientas populares de valoración económica, como la valoración contingente y los métodos de estimación de precios sombra, han intentado asignar valores monetarios a los diversos bienes y servicios proporcionados por la naturaleza. Sin embargo, por un lado, la adecuación de estos enfoques para considerar los múltiples y complejos valores de la naturaleza sigue siendo materia de discusión, y, por otro lado, existe cierto debate sobre las implicaciones éticas de monetizar los diversos valores intrínsecos y culturales que proporciona la naturaleza. Estos desafíos han dado como resultado valores de no mercado que se subestiman o se excluyen por completo de las evaluaciones económicas. Este hecho es particularmente problemático para los casos de adaptación que se ocupan de soluciones no técnicas, como la conservación del entorno, ya que la falta de captura de la verdadera magnitud del coste y de los beneficios, a menudo resulta en soluciones parciales o menos prioritarias que soluciones más verificables (por ejemplo, tecnológicas o medidas de infraestructura).

Chiabai et. al. (2013) presentan un enfoque novedoso que promueve la conservación del entorno natural en la planificación del uso del terreno mediante la aplicación de tasas de descuento específicas para cada lugar. Este enfoque se basa en la propuesta de carácter normativo de que el valor social de un terreno natural debe ser al menos igual al precio de mercado de un terreno adyacente con características ambientales similares a las que se les ha otorgado permiso para ser desarrollado. Argumentan que, en el caso de tener dos terrenos idénticos ubicados en la misma unidad administrativa, si a uno de los dos se le otorga permiso para desarrollarse (o urbanizarse), las distorsiones en el mercado y otras externalidades que esto generaría harían que los dos terrenos fueran valorados de manera diferente. Esta situación genera una anomalía con implicaciones éticas y ambientales potencialmente graves, ya que incentiva a la urbanización de los entornos naturales en lugar de promover el uso y/o la restauración de entornos urbanos ya existentes. El Principio de Equivalencia (EP) argumenta que el valor de ambos terrenos debería ser, al menos, equivalente pues las generaciones futuras probablemente obtengan una utilidad y un valor económico semejante para ambos. El beneficio principal del EP es que logra evitar el tener que hacer suposiciones sobre el bienestar esperado de generaciones futuras, es decir, sobre su tasa de consumo, y asimismo, evita hacer suposiciones sobre la magnitud de los impactos inciertos del cambio climático, los cuales podrían materializarse en el futuro de manera distinta a las predicciones.

El Capítulo 3 explora la aplicación práctica del EP de Chiabai et al. (2013) en diferentes entornos naturales en Europa, y basa su discusión en la siguiente pregunta:

RQ2: ¿En qué medida se puede aplicar de forma razonable el Principio de Equivalencia en todas las regiones de Europa para promover la protección de entornos naturales en la planificación del territorio?

Capítulo 4: Efectos en el empleo, en la equidad y en la aversión al riesgo

Existen muchas dudas sobre la idoneidad del uso del CBA como método para valorar las inversiones públicas con implicaciones ambientales y de cambio climático. Como lo demostrarán los resultados de la revisión sistemática realizada en el Capítulo 2, la mayoría de los CBA de adaptación se centran en evaluaciones simplistas de costes y beneficios (es decir, costes de inversión directa y daños evitados por el cambio climático). Sin embargo, hay tres dimensiones que, a menudo, no se tienen en cuenta.

La primera, es el efecto de las medidas de adaptación en el empleo. Los efectos sobre el empleo a menudo no se incorporan en los análisis de coste-beneficio de las medidas de adaptación, debido a la suposición implícita de que no existen distorsiones en el mercado laboral, como el desempleo involuntario. Por esta razón, el CBA no puede capturar ninguno de los beneficios de la adaptación relacionados con el empleo, particularmente en regiones con altos niveles de desempleo involuntario, donde las políticas y proyectos de adaptación podrían producir beneficios significativos para la sociedad, es decir, al crear empleos y mejorar la oferta laboral. La segunda, se relaciona con la consideración de la equidad en las evaluaciones de adaptación. El enfoque de resultado agregado de los CBA crea un sesgo hacia programas con beneficios generales altos y costes bajos, independientemente de cómo se distribuyan esos costes y beneficios en toda la sociedad. Esto ha conllevado la toma de decisiones de adaptación que han acentuado desigualdades sociales y económicas preexistentes. La tercera, se relaciona con el tratamiento de las preferencias de riesgo dentro de los CBA. La aversión al riesgo es una suposición típica en economía, dado que las personas están dispuestas a pagar para reducir su riesgo ante eventos desfavorables (por ejemplo, pagar un seguro para limitar las pérdidas por inundaciones). De esta forma, estar expuesto al riesgo representa un coste para las personas con aversión al riesgo. Este valor, a menudo se descuida en el CBA de la adaptación, lo que puede resultar en una subestimación de los beneficios de la adaptación.

El Capítulo 4 explora estas tres dimensiones del CBA. Específicamente, propone metodologías bien establecidas para integrar los efectos del empleo, de la equidad y de la aversión al riesgo dentro del CBA. Para ello, usa un caso de estudio de adaptación en Bilbao (País Vasco, España) con el que examina cómo la inclusión/exclusión de estos tres valores afecta los resultados de la decisión. Su discusión se basa en la siguiente pregunta:

RQ3: ¿En qué medida la integración de los efectos en el empleo, la equidad y la aversión al riesgo dentro del CBA afecta los resultados de las decisiones de adaptación?

Capítulos 5 y 6: Marcos de riesgo, experiencia y toma de decisiones de adaptación

Los eventos climáticos más frecuentes y graves, como las inundaciones extremas, las olas de calor, o las sequías prolongadas, ya generan efectos devastadores en todo el planeta. A medida que aumenten las temperaturas, se espera que estos efectos se intensifiquen, y muchos científicos han expresado serias preocupaciones sobre la naturaleza potencialmente catastrófica de sus impactos futuros. Sin embargo, estos riesgos son complejos y a menudo difíciles de interpretar. La adaptación al cambio climático dependerá en gran medida de cómo se comuniquen estos riesgos, así como de cómo los diferentes actores de la sociedad (como los responsables políticos o los ciudadanos) los interpreten y respondan a ellos.

A lo largo de los años, la comunicación sobre el riesgo climático se ha centrado en el uso de las evaluaciones de expertos basadas en "estadísticas de riesgo". Sin embargo, los estudios científicos en esta materia han demostrado que existe una diferencia importante entre las evaluaciones de riesgo de los expertos, que son objetivas, y la percepción social de dichos riesgos, que son subjetivas. Esto podría explicar por qué muchas personas carecen de motivación para actuar sobre el cambio climático y se sienten en desconexión con éste. Desde la investigación se ha sugerido el uso de esquemas de comunicación de riesgo que procesan la información desde una perspectiva más basada en las experiencias. Existen evidencias que sugieren que las experiencias magnifican los riesgos percibidos con un consecuente efecto significativo sobre la percepción y el comportamiento frente al riesgo. Dos ejemplos de esto son, la experiencia previa con eventos climáticos, y las emociones. Sin embargo, un cierto nivel de razonamiento analítico es también un requisito previo importante para la toma de decisiones bajo riesgo e incertidumbre. Dado que los sistemas experienciales y cognitivos tienden a competir cuando procesan información incierta, será necesario encontrar el equilibrio correcto entre los factores experienciales y otros aspectos cognitivos importantes clave para procesar el riesgo.

Mediante el diseño de dos experimentos económicos, los capítulos 5 y 6 tienen como objetivo contribuir a la investigación actual sobre la toma de decisiones en condiciones de riesgo e incertidumbre. Para ello, se examinarán los efectos cognitivos y experienciales de enmarcar la de comunicación de riesgo y el impacto posterior que esto puede tener en la toma de decisiones de inversión en medidas de adaptación. Los capítulos 5 y 6 exploran la siguiente pregunta:

RQ4: ¿Cuáles son los efectos cognitivos y experienciales de las formas en la que se enmarcan los riesgos y la experiencia, y en qué medida influyen en las decisiones de inversión en medidas de adaptación?

Acknowledgements

I would like to take this opportunity to thank the many people who have been instrumental in shaping this thesis and in supporting me over these past four years. Without them, this work would never have been done.

I first want to thank Ibon Galarraga and Anil Markandya, my two supervisors, for your endless guidance, support and encouragement. Throughout these years, you have taught me that research is a non-linear process, one that involves constant learning, commitment and perseverance. Thank you for always making time for me, without your patience, expertise and invaluable insights during this process this thesis would only be a fraction of what it is today. A special thank you also to Elisa Sainz de Murieta for being my silent supervisor over the years.

I am also indebted to my tutor, Alberto Ansuategui, and Marta Escapa, for all their efforts in making the PhD process as seamless and stress-free as possible.

I would also like to express my deep gratitude to Steffen Kallbekken, Jaromir Kovarik and Bernardo García Pola for introducing me to, and teaching me about the ins and outs of experimental research. The best parts of my PhD were spent in the lab.

This thesis would (literally) not have been possible without the institutional support of the Basque Centre for Climate Change, and all the incredible people I have met as a result of working here over the past four years. Dirk-Jan Van de Ven, Jon Sampredo and Itxaso Ruiz thank you for being the best office mates and for all of the great banter and welcomed distractions. To Bosco Lliso and Alevgul Sorman, I probably would have given up much sooner were it not for the two of you. I am glad that we found each other. At BC3, outside of BC3, and in the world of D&D too.

I would like to thank my parents, Ajay and Priya, and my brothers Ishan and Zuben, whose continued support and unconditional love has helped shape me into the person I am today. Thank you for always showing me that the sky is the limit. This achievement is as much yours as it is mine.

Finally, I want to thank my love and partner in crime, Benjamin Patrick. Thank you for putting up with me over these years, for always pushing me to be a better version of myself, and for always making me feel supported, listened to (even during my endless morning monologues) and loved.

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Chapter I: Introduction

The latest Technical Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) has confirmed that there is a clear anthropogenic influence on the climate, and that this is causing an unequivocal warming of Earth's atmosphere and oceans (Field et al., 2014). As global temperatures rise, communities across the world are facing unprecedented impacts. More frequent and extreme climate events, such as droughts, heat waves, storms, and flooding, are being felt across the globe, with huge economic, health, social and environmental implications. The international community has responded by bringing together scientific and political leaders through major events such as the Rio and Rio+ Earth Summits, annual United Nations Climate Change Conferences of the Parties (UNFCCC, COPs), and IPCC meetings and technical assessment reports, which have all played a major role in positioning climate change as a priority issue in national political agendas worldwide.

Over the last few decades climate change adaptation[1] has received comparatively less attention than mitigation in science and policy circles, with some concerns that "it presumably implies defeat in the battle against evil emissions" (Tol, 2005). But climate change is already having devastating impacts on communities throughout the world, and even with a limit on global temperature rises, impact and adaptation costs are expected to increase substantially in coming years, up to 2-3 times more than the previously expected annual estimate of $70-$100 billion by 2050 (UNEP, 2014). Recently, international bodies have emphasised the relevance for nations to consider adaptation with the same priority as mitigation, based on the recognition that it can substantially reduce the costs of impacts, is likely to have significant ancillary benefits, and can also increase resilience to long-term changes in climate. However, adaptation is also likely to require forward-looking investment and planning responses that go beyond short-term actions. Many countries are thus beginning to define collective and long-term adaptation goals for reducing risks, improving adaptive capacity, and increasing resilience in the face of climate change.

In Europe, the European Commission's White Paper (European Commission, 2009) and European Union (EU) Strategy on Adaptation to Climate Change (European Commission, 2013) were developed to promote the mainstreaming of adaptation into relevant EU policies and programs and to help EU member states establish comprehensive adaptation strategies, with a particular focus on cities. To date, 25 European Member States have adopted National Adaptation Strategies (NASs) and 15 have developed National Adaptation Plans (NAPs) (European Environment Agency, 2018). Adaptation was

[1] The IPCC defines adaptation as "the process of adjustment to actual or expected climate and its effects, which seeks to moderate or avoid harm or exploit beneficial opportunities" (Field et al., 2014).

also an important component of the 2015 landmark Paris Agreement, signed by all UNFCCC member states at the 21st COP in Paris, France. The Agreement states that all Parties must engage in adaptation planning and implementation, and should do so through, for example, the development of national adaptation plans, vulnerability assessments, monitoring and evaluation, and economic diversification.

Despite efforts to mainstream climate change adaptation into local and national policies, it remains a complex subject-area, challenged by numerous scientific and political constraints. For one, adaptation is extremely diverse in nature. As shown in Table 1, adaptation constitutes a combination of top-down and bottom up measures, which can be autonomous or planned, tailored to specific hazards or sectors, and made up of different temporal and spatial scales. Moreover, adaptation involves actions throughout society, involving citizens, actors in public and private sectors, and governments.

Table 1. Examples and characteristics of climate change adaptation

Hazards	*Measure types*	*Examples*	*Timescales*	*Implementation scales*	*Type*
Pluvial and fluvial floods, extreme storm	Infrastructural	Drainage systems; property-level measures (i.e. wet and dry proofing homes)	Short-medium	Local-regional	Autonomous/planned
events	Ecosystem-based	Floodplain conservation	Medium-long	Local-national	Planned
	Services	Resettlement of vulnerable communities; community preparedness and capacity building	Medium-long	Local-regional	Autonomous/ planned
	Technological	Rainwater harvesting	Short-medium	Local	Autonomous/planned
	Informational	Early-warning systems	Medium-long	Local-national	Planned
Sea-level rise	Infrastructural	Hard barriers (dikes, revetments, levees, sea-walls, groins, bulkheads, revetments and geo-textiles, land elevation)	Medium-long	Local-regional	Planned
	Ecosystem-based	Beach nourishment; mangroves	Short-long	Local-regional	Planned
	Services	Resettlement of vulnerable communities	Medium-long	Local-regional	Autonomous/ Planned
Drought	Technological	Rainwater harvesting systems; wastewater reuse and recycling	Short-medium	Local-regional	Autonomous/planned
	Economic	Subsidies	Medium	Regional-national	Planned
Heat waves	Ecosystem-based	Green roofs; green facades; green areas	Short-long	Local-regional	Autonomous/planned
	Informational	Early warning systems	Medium-long	Local-national	Planned
	Technological	Cooling systems (air conditioning)	Short	Local	Autonomous
	Services	Relief centres	Short-medium	Local-national	Planned
	Infrastructural	Property-level measures (i.e. cooling materials, white roofs)	Short	Local	Autonomous

What complicates adaptation further, is the fact that climate change impacts will be mainly felt at local scales, which means that responses must also consider local specificities, such as regional topographies, economic structures and household adaptive capacities (Hallegatte et al., 2011). At the local-level, cities are a fundamental focal point of adaptation planning, not only since they represent important hubs of economic activity and house much of the world's population, but also since they are especially vulnerable to the impacts of climate change. For one, many cities are situated along coastal zones or close to riverbanks, making them extremely susceptible to inland and coastal flooding, which in severe cases may act to displace large communities of people. Large areas of cities are also composed of non-porous surfaces, which makes it harder to deal with periods of high precipitation and in turn may lead to disruptions to critical services and infrastructures. Due to their high population densities and concentration of built infrastructure, cities are also prone to the so-called urban heat island effect. This makes cities significantly warmer than surrounding rural areas, and leads to increased rates of morbidity and mortality, particularly among vulnerable or marginalised groups, during times of heat stress (Sainz de Murieta et al., 2014).

Designing and implementing adequate adaptation strategies in cities and similar urban regions, will require a systemic assessment of climate change impacts, as well as adaptation costs and benefits, at local scales. While there have been attempts to synthesise adaptation research, there is a wide variation in studies related to the types of questions, approaches, and sectors investigated (Hunt and Watkiss, 2011). In particular, research syntheses on the economic aspects of adaptation, related to the feasibility, costs and benefits, effectiveness, and the likely state of implementation of measures is still in its infancy, and remains far less mature than that on the economics of mitigation (Agrawala et al., 2011). Indeed, conducting comparative economic assessments of adaptation is challenged by the absence of a comprehensive, universal framework for conducting adaptation assessments, which has meant that estimates vary considerably depending on types of methods, considerations of future climate change and related uncertainties, and differences in spatial, sector, and temporal contexts and objectives (Markandya and Watkiss, 2009; Watkiss et al., 2015).

The limited evidence-base suggests that most economic assessments of adaptation tend to be based on traditional economic approaches, such as cost-benefit analysis (CBA). However, critics argue that in their current form, such tools face a number of methodological issues and are inadequate for dealing with the various unprecedented decision dimensions of climate change. For one, approaches are ill-suited for dealing with the large temporal and spatial scales involved with climate change and are often too simplistic for dealing with aspects related to distributional and non-market effects, intra- and inter-generational preferences, and dimensions of risk, equity and fairness in assessments. Secondly, such approaches tend to assume that adaptation decisions will be driven largely by profit maximisation and notions of so-called rational decision-making, despite an emerging body of evidence from behavioural and experimental research, which suggests that human decision-making under risk and uncertainty is much more complex than this (Gowdy, 2008). Approaches based on such assessment objectives raise questions as to whether current valuation methods for adaptation are sufficiently robust enough to guide policy interventions on climate change.

Over the course of five chapters, this thesis explores some of the critical questions surrounding the economic and behavioural dimensions of climate change adaptation and decision-making, with a special focus on cities and similar urban settings. Chapters 2, 3 and 4 focus broadly on exploring and further developing economic assessment methods to support adaptation decision-making, while Chapters 5 and 6 explore insights from behavioural economics and use experimental approaches for testing adaptation investment decisions under risk and uncertainty. These chapters are covered by two broad methodological phases; the first, focuses on an exploration of previous studies and existing economic approaches and tools (phase I), while the second phase centres around the use of economic experiments in order to provide empirical contributions to the literature (phase II). An overview of research areas, topics, and methodological phases covered by the various chapters of this thesis is shown in Figure 1.

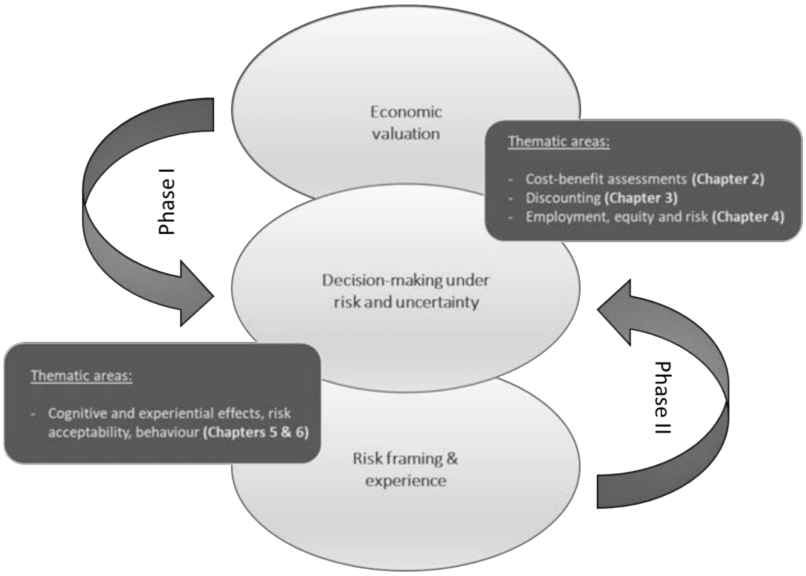

Figure 1. Overview of adaptation research areas covered in this thesis under two separate methodological phases (I & II)

Section 1.1 will introduce these chapters in further depth. The key research gaps and research questions covered by each chapter will be explored first (section 1.1.1 to section 1.1.4), before looking deeper into the approaches used within each of the two broad methodological phases covered in this thesis (section 1.2).

1.1. Background and research motivation

1.1.1. Cost-benefit assessments of adaptation (Chapter 2)

Helping cities to plan for adaptation will require both a detailed assessment of climate change impacts across different sectors and groups, as well as an evaluation of the costs and benefits of different measures at local levels. Appraisals of different adaptation aspects have certainly increased over recent years (Carter, 2011; Hunt and Watkiss, 2011; Markandya and Watkiss, 2009; Solecki et al., 2011), but the majority of studies tend to focus on synthesising qualitative reports on large-scale adaptations, or on reviewing lessons from, and trends in, adaptation governance (Berrang-Ford et al., 2015). There is a fundamental gap in research syntheses covering cost-benefit assessments of adaptation at the local-level, and specifically, there are no studies which explore the practical application of cost-benefit analysis for adaptation, despite its frequent use as a decision-support tool for assessing the feasibility of measures.

Conducting a critical and comparative analysis of CBA in an adaptation context is important for at least two reasons. Firstly, there is far more to economically efficient adaptation than a simple comparison of costs and benefits. Assessments dealing with the economic efficiency of various adaptations must consider aspects related to, for example, the distribution of costs and benefits, the costs and benefits of goods and services not expressed in market values, and the timing of adaptation actions. Improper consideration of these types of elements could risk seriously underestimating both the costs and benefits of adaptation (Adger et al., 2005). Improving these estimates will help to assess the full costs of climate change, comprised of three interdependent components: the cost of adaptation, the cost of mitigation and the cost of residual climate change. Secondly, it can help to provide normative guidance on the efficiency of climate policy mixes, assisting policymakers to allocate resources efficiently between different adaptation measures, as well as between different adaptation and mitigation measures.

Chapter 2 of this thesis explores the evidence-base related to cost-benefit assessments of adaptation measures in cities, and specifically, focuses on the viability of CBA as a decision-support tool for adaptation. The chapter aims to address the following research question:

RQ1: How accurate is the information derived from cost-benefit assessments of adaptation, and to what degree does it form a credible basis for adaptation plans and investment decisions in this field?

1.1.2. Site-specific discount rates for natural land conservation (Chapter 3)

Climate change poses a significant threat to species and ecosystems across the globe. Habitat destruction, alteration of key ecological processes, the spread of harmful invasive species, and the emergence of new pathogens and diseases, represent just some of the leading threats to biodiversity and natural systems caused by climate change (Wilcove et al., 1998). Ongoing urbanisation further intensifies these threats, as cities and urban populations continue to expand and grow, leading to large-scale conversions of rural to urban landscapes[2]. In light of this, various adaptation strategies have been proposed for managing the impacts of climate change and urban development on natural systems. In particular, ecosystem-based solutions, such as establishing habitat buffers (restoring or protecting areas adjacent to current habitats) and wildlife corridors, restoring degraded habitats, and expanding protected areas, have been proposed as effective strategies for conserving the natural state of ecosystems and minimising human impact. These solutions are unique from a climate perspective, due to their ability to contribute to both adaptation and mitigation objectives simultaneously. Managing ecosystems through land conservation can not only reduce emissions that might otherwise result from conversion to more intensive land-uses, land degradation or natural disturbance, but can also promote increased carbon sequestration (Hudiburg et al., 2009; Lal, 2004), enhance the resilience and adaptive capacity of species and ecosystems, and maintain the provision of important ecosystem services (Cameron et al., 2017; Millar et al., 2007; Stein et al., 2013).

Despite the considerable benefits associated with natural land conservation, we continue to see a decline in natural lands and ecosystems across regions. Since 1992, around 3% of (semi-)natural vegetated land worldwide has been lost to other types of land-uses, with agricultural and urban expansion being primary drivers (OECD, 2018). Based on historical trends, recent estimates suggest that compared to 2013, the global urban area is expected to increase by roughly 40-67% by 2050, with continuing trends expected to see this reach an increase of over 200% by the end of the century (Li et al., 2019).

Now more than ever, there is an urgent need to find adequate ways in which to account for nature's diverse values in land management decisions. Over the years, popular economic valuation tools, such as contingent valuation and shadow pricing methods, have attempted to assign monetary values to the diverse goods and services provided by nature. But the adequacy of these approaches for reflecting the multiple and complex values of nature has been heavily debated over the years, and concerns have been raised over the ethical implications of monetising the various intrinsic and cultural values that nature provides. Where and when these approaches are applied is also limited by the technical expertise and resources required to carry out assessments. The challenges of integrating non-market items when valuing public investment decisions, means that often-times values are either underestimated or

[2] The construction of roads, buildings and farms, for example, can act to restrict natural migration routes for species looking to track favourable climate conditions (Ibáñez et al., 2006; Myers, 1992; Root and Schneider, 2002)

excluded altogether from economic assessments. This is particularly problematic for adaptation cases that deal with non-technical solutions such as land conservation, since failure to capture the true magnitude of costs and benefits often results in such solutions being ranked lower or afforded less priority than other more verifiable solutions (Watkiss et al., 2015). These issues have led to a growing academic literature centred around the valuation of nature (Fisher et al., 2009; Seppelt et al., 2011), and increasing effort is being put towards developing approaches that are able to capture its multiple value dimensions (i.e. intrinsic, relational, instrumental) as well as the values of relevant stakeholders within decision-making (Jacobs et al., 2016).

An alternative approach has been proposed by Chiabai et al. (2013), for promoting natural land conservation within land-use planning through the use of site-specific discount rates. The approach is based on the normative proposition that the social value of natural land should be at least the same as the market price of an adjacent land with similar environmental characteristics that has been granted permission for development. The theory argues that when one of two identical pieces of land located in the same administrative unit has been granted permission for development, market distortions stemming from regulations and externalities arise that will cause these two lands to be valued differently. This situation generates an anomaly with potentially grave ethical and environmental implications, since it incentivises the urbanisation of natural lands rather the use or restoration of existing urban lands. The so-called Equivalency Principle (EP) argues that the present value of both lands should be at least equivalent, with future generations likely to derive equal utility and economic value from them. An important benefit to this approach is that is avoids making assumptions about the expected welfare or growth rate of consumption of future generations, and the magnitude of projected uncertain impacts such as from climate change, which might materialise differently in the future.

While Chiabai et al. (2013) sets the theoretical foundations for the EP, Chapter 3 explores the practical application of the EP across different land types in Europe, and bases its discussion on the following research question:

RQ2: To what extent can the Equivalency Principle be reasonably applied across regions to promote the protection of diverse natural land types in land-use planning?

1.1.3. Employment effects, equity and risk-aversion (Chapter 4)

There are many concerns over the use of CBA for valuing public investments with environmental and climate change implications (Ackerman and Heinzerling, 2001; Hanley, 1992). Much of the academic literature that broadly explores the use of CBA for environmental decision-making has centred around two primary concerns; discounting and non-market valuation. These have been touched upon in section 1.1.2 and are discussed in further depth in Chapter 3. There is significantly less discourse however, which focuses on the use of CBA specific to the adaptation context, wherein other pertinent issues may arise. As the findings from the systemic review conducted in Chapter 2 will demonstrate, most CBA of adaptation tends to consider simplistic assessments of costs and benefits. These largely relate to costs and benefits with direct market values, and in some cases, may also include certain non-market (i.e. social, health and environmental) items, that can be easily monetised.

There are, however, three important dimensions of adaptation that are rarely considered within cost-benefit assessments. The first relates to the effect of adaptation on employment. Adaptation projects will impact labour markets by, for example, directly creating jobs, facilitating the creation of jobs, or improving labour supply. Adaptation is likely to have especially significant effects on labour markets with high levels of unemployment, wherein policies and projects could produce significant benefits to society. Employment effects, however, are often missing in cost-benefit assessments of adaptation, due to the implicit assumption that distortions in the labour market, such as involuntary unemployment, do not exist. For this reason, CBA is unable to capture any of the employment related benefits of adaptation.

A second, but equally relevant issue, relates to the consideration of equity within adaptation assessments. Effects on well-being are often considered within CBA through monetary equivalents, i.e. the total amount that individuals are willing to accept (in the case that they are negatively affected) or willing to pay (in the case that they are positively affected) for certain policies or programs. This focus on aggregate benefit leads CBA to favour programs with a positive sum of monetary equivalents, irrespective of how costs and benefits are distributed throughout society. This is particularly problematic in cases where adaptation may affect people in diverse income groups, since those with higher incomes will be able to pay more for policies or programs that they prefer, those with lower incomes will almost always be at a disadvantage. Adaptation decisions based on current feasibility assessments have not only led to actions that reinforce existing inequalities, but also do little to relieve underlying social and economic vulnerabilities, in some cases even exasperating them (Adger et al., 2007, 2003). As it stands, climate change disproportionately affects lower-income countries, as well as poor communities in high-income countries, which should position issues like equity and fairness as central focus points of climate-related decision-making.

A third problematic area of adaptation assessments concerns the treatment of risk preferences. Risk-aversion is an implicit assumption in economics, such that people are willing to pay to reduce their risk from certain unfavourable events (e.g. pay insurance to limit losses from flooding). Thus, in such cases, being exposed to certain risks would represent a cost to risk-averse individuals. Despite this assumption, CBA typically ignores risk-aversion. This is based on the supposition that governments are risk-neutral when it comes to risky public investments with uncertain benefits and costs, since any foreseeable risks will be spread out among large populations and converge to zero. This rational however, does not hold in cases involving projects that reduce pre-existing environmental uncertainty. Climate risks are not evenly spread across populations, meaning that adaptation projects can provide risk-reducing benefits to affected risk-averse populations, which can differ according to the type of adaptation measure and where it is implemented. Not accounting for risk-aversion therefore, risks underestimating the benefits of adaptation, which may subsequently also affect the overall efficiency of adaptation investments within CBA.

Chapter 4 explores these three missing dimensions of CBA in greater depth. Specifically, it proposes well-established methodologies for integrating employment effects, equity and risk-aversion within CBA, and, using a case study of an adaptation project in Bilbao (Basque Country, Spain), it examines how including (or not including) these values can affect decision outcomes. Its discussion is based on the following research question:

RQ3: To what extent can integrating employment effects, equity and risk-aversion within CBA, affect adaptation decision outcomes?

1.1.4. Risk framings, experience and adaptation decision-making (Chapters 5-6)

More frequent and severe climate-related events, such as extreme floods, heat waves and drought, are already having devastating impacts across the globe. As temperatures rise, these effects are expected to intensify, and many scientists have expressed serious concerns over the potentially catastrophic nature of future impacts. But these risks are often difficult to interpret, particularly given that current estimations of future climate impacts are largely probabilistic and involve varying degrees of uncertainty. Adapting to the future consequences of climate change will, to a great extent, depend on how risks are communicated, as well as how different actors in society (i.e. policy makers and citizens) interpret and respond to them.

Over the years, climate risk communicators have relied predominantly on conveying expert assessments of so-called 'risk statistics'. Despite these efforts, studies have shown that individuals lack motivation to take action on climate change, primarily due to a reduced personal and emotional connection with the issue (Lorenzoni et al., 2007; Lorenzoni and Pidgeon, 2006). The dichotomy between expert assessments of risks, which tend to be objective, and public perceptions of risks, which tend to be subjective, may help to explain why normative approaches to risk communication are not having desired effects. To address this, a move from risk communication devices that rely on purely cognitive interpretations of risk towards ones aimed at more experiential forms of information processing, so-called 'risk-as-feelings', have been proposed (Loewenstein et al., 2001; Slovic et al., 2004). There are some concerns however, that this may lead to cognitive biases and errors in judgment prone to more irrational forms of decision making.

Some emerging theories postulate that dominant technocratic approaches to risk lack normative-ethical dimensions, and by targeting experiential modes of thinking in risk communications, a moral understanding of risks and impacts can be achieved that leads to decisions that are both emotional and rational (Roeser, 2012, 2010). There is certainly evidence to suggest that experiential factors can make risks more salient, and subsequently, can have a significant effect on risk perceptions and behaviour. Two primary examples being previous experience with climatic events (Burningham et al., 2008; Harvatt et al., 2011; Kellens et al., 2011; Lawrence et al., 2014; Siegrist and Gutscher, 2008, 2006; Spence et al., 2011), and emotions (Cooper and Nisbet, 2016; Leiserowitz, 2006; Miceli et al., 2008; Otieno et al., 2014; Siegrist and Gutscher, 2008; Smith and Leiserowitz, 2012; Spence and Pidgeon, 2010; Takao et al., 2004; Terpstra, 2011; van der Linden, 2014; Zaalberg et al., 2009). However, a certain level of analytical reasoning is also an important prerequisite for decision-making under risk and uncertainty, and, since experiential and cognitive systems tend to compete when processing uncertain information (Marx et al., 2007), finding the right balance between experiential factors and other important cognitive aspects necessary for processing risk is likely needed.

There are numerous studies centred around the various drivers of climate risk perceptions and hypothetical behaviour, but the evidence base on the experiential and cognitive effects of climate change risk framings is still in its infancy, and there is a dearth in experimental research which tests preferences and communication formats across different audiences and on actual behaviour (Demeritt and Nobert, 2014; Spiegelhalter et al., 2011). Through the design of two economic lab experiments, Chapters 5 and 6 of this thesis aim to contribute to the body of research on decision making under risk and uncertainty by examining the cognitive and experiential effects of different risk communication framings and experience, and the subsequent impact this may have on adaptation investment behaviour. While the specific research questions addressed by each experiment can be found in the individual chapters, broadly speaking Chapters 5 and 6 explore the following question:

RQ4: What are the cognitive and experiential effects of risk framing and experience, and to what extent do they influence adaptation investment behaviour?

1.2. Methods

This section will first begin with a summary of the research gaps and research questions outlined in section 1.1. After which, it will provide an overview and justification for the methodological steps taken to address each research question, before concluding with highlights of some of the general challenges and learning experiences encountered over the course of this research.

1.2.1. Summary of research gaps (RG) and questions (RQ)

RG1: Despite the growth in studies and reviews related to the economics of adaptation, the literature still lacks a systematic research synthesis of the current evidence-base on the costs and benefits of local-level adaptation and the viability of commonly used economic valuation tools, such as CBA, for making adaptation decisions.

RQ1: How accurate is the information derived from cost-benefit assessments of adaptation, and to what degree does it form a credible basis for adaptation plans and investment decisions in this field?

RG2: Climate change and urbanisation are degrading natural systems across the world at an unsustainable rate. An important focal point of climate change adaptation, therefore, is centred on how to adequately represent the multiple and important value dimensions of natural lands in decision-making in order to promote their protection. Current economic valuation tools have been criticised for underestimating the true value of nature, and while there are ongoing efforts to develop more holistic valuation procedures, these are not necessarily easily integrated within decision-making processes. There is an urgent need for innovative decision tools that promote protection efforts, and which can be easily integrated into feasibility assessments (i.e. CBA) for land-use planning.

RQ2: To what extent can the Equivalency Principle be reasonably applied across regions to promote the protection of diverse natural land types in land-use planning?

RG3: Despite the significant debate on the use of CBA for environmental assessments, there is considerably less discourse centred around the use of CBA for adaptation decision-making. The use of CBA for valuing adaptation investments tends to rely on simplistic assessments of costs and benefits, and rarely considers effects related to employment, equity and risk-aversion. Integrating these factors within CBA may help to avoid adaptation decisions which reinforce or exasperate existing inequalities and promote those which help to relieve underlying (i.e. social and economic) vulnerabilities.

RQ3: To what extent can integrating employment effects, equity and risk-aversion within CBA, affect adaptation decision outcomes?

RG4: Despite efforts to communicate risks, studies suggest that people may feel disengaged with the issue of climate change, which in turn reduces their motivation to act on it. This points to a dichotomy between expert assessments of so-called 'risk-statistics', which tend to be objective and analytic, and public perceptions of risks, which tend to be subjective and experiential. This signals a need for risk communications that balance cognitive and experiential forms of information processing, which could prove to be more effective. There is an extensive literature base covering the multiple drivers of risk perceptions and behaviour, with evidence to suggest that experiential factors, i.e. experience and emotions may be significant drivers of perceptions and adaptive behaviour. But there is insufficient empirical research, i.e. stemming from controlled experimental settings, on the experiential and cognitive responses to different formats of risk information, and their ability to motivate action across different audiences.

RQ4: What are the cognitive and experiential effects of risk framing and experience, and to what extent do they influence adaptation investment behaviour?

1.2.2. Stages of data collection and analysis

A primary motivation of this PhD was to investigate, in a broad sense, the interplay between the economics and decision-making of adaptation. Specifically, I wanted to explore how economic tools are facilitating, advancing and limiting effective adaptation responses in cities, and to identify areas where economic approaches could be improved in order to support decision-making on adaptation. Given the multiple dimensions of adaptation research, it became obvious at the early stages of this PhD that I would be taken down many different lines of questioning. It seemed right therefore, to begin with the broadest research question, which would allow me to explore various schools of thought and gain a more comprehensive understanding of the literature surrounding adaptation. At the same time, it would enable me to develop more focused research questions as the thesis progressed. For the same reason, I wanted to explore various scales of analyses, moving from larger scales to more refined localised assessments of adaptation. The resulting chapters of this thesis demonstrate the different branches of adaptation research that I explored throughout the course of my PhD, with each chapter centred around a different and unique aspect of adaptation economics and covering a different scale of analysis (Figure 2).

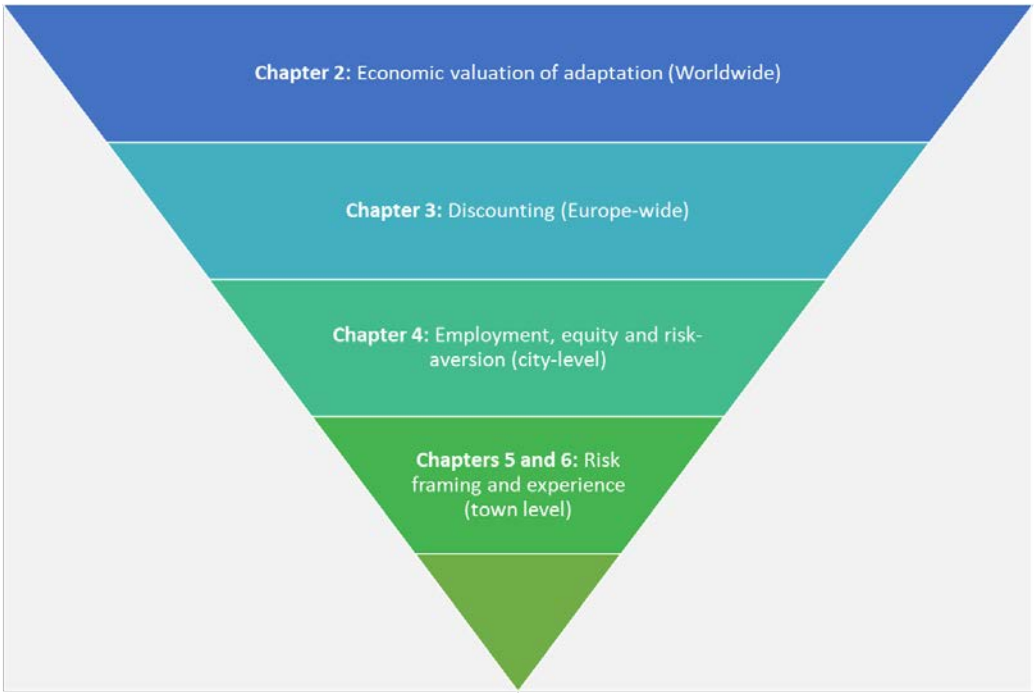

Figure 2. Summary of research topics and scales of analyses covered within each chapter

I use a series of methodological approaches throughout each of the following five chapters for assessing different interactions between adaptation economics and decision making. In general, these can be separated into two main phases. Phase I reflects the beginning stages of the PhD, focused mainly on building an understanding of the adaptation literature. Thus, the methods I employ during this phase are largely centred around conducting in depth literature searches, identifying key research gaps, and exploring the use of existing economic approaches and theories. Phase II on the other hand, reflects a more advanced stage of the PhD, where my knowledge surrounding adaptation is more mature, and where I seek to develop new approaches and offer empirical contributions to the literature. Thus, in Phase II I look into how the adaptation literature connects with other fields and disciplines, I explore for example, connections between economics and psychology, and I design and implement economic lab experiments for testing some of these relationships. A summary of these two phases and how they tie into the various chapters of this thesis is provided below.

<u>Phase I:</u>

An important first step of research into this field was to explore and conduct a synthesis of the current evidence-base on the economics of adaptation. Despite the growing literature surrounding the costs and benefits of adaptation, there are still many urgent questions surrounding these estimates, e.g. what assumptions are built into assessments? And how do they account for complex aspects such as uncertainties, risks and intergenerational preferences? Reviews on adaptation have increased over the years, but these are mainly based on assessments of actions at larger scales, and few studies use systematic review methods that are transparent, objective and limit reviewer bias. The few systematic reviews on adaptation that do exist, are also concerned mainly with reviewing lessons and trends in adaptation governance (Berrang-Ford et al., 2015). I recognised a fundamental gap in systematic literature reviews covering cost-benefit assessments of adaptation, particularly at the local-level. There is certainly a great need for comprehensive syntheses of existing research and tools for evaluating progress on climate change adaptation. Understanding the current state of the literature on adaptation can help to: identify if and where adaptations are being implemented, monitor the progress and effectiveness of adaptation responses, facilitate the comparison of adaptations across regions and sectors, locate areas of high impact and/or vulnerability, understand key barriers and drivers of implementation, and inform policy making on the current status and gaps in adaptation action (Berrang-Ford et al., 2015, 2011; Biesbroek et al., 2013; Pielke Jr et al., 2007).

Thus, the objective of Chapter 2 was to explore cost-benefit assessments on adaptation at local levels, and through a systematic review, critically assess the advantages and disadvantages of valuation approaches for decision-making in this context. There are various approaches to research synthesis and review, with no formal guidelines on the suitability of approaches for different literature types. In many cases, literature reviews are based on inductive approaches, which tend to be interpretive rather than aggregative, and thus prone to researcher bias. In contrast, systemic reviews are used to conduct focused assessments of the literature and seek to answer a specific research question using pre-defined eligibility criteria for documents, using methods that are explicitly outlined and reproducible (Cooper and Hedges, 1993; Gough et al., 2012). The approach outlined in Chapter 2, was considered especially useful for the handling and assessment of both qualitative and quantitative data, and for identifying specific trends, gaps and opportunities for later research. A detailed summary of the methodological approach used in Chapter 2 can be found in Appendix I.

The systematic review conducted in Chapter 2 and its subsequent findings, helped in highlighting the research gaps and in contextualising the research questions later addressed in Chapters 3 and 4. As the results of Chapter 2 will demonstrate, the discount rates employed in CBA of adaptation fall within a wide spectrum of values, with the majority of assessments considering rates of 5% or higher, and a very small selection of studies considering rates below 2%, or rates that decline over time. In addition, studies tend to favour short to medium timescales, with a limited number of cost-benefit assessments based on time frames over 50 years. The use of high discount rates in combination with short- or medium-term time considerations, specifically in relation to ecosystem or nature-based adaptations, is problematic, since these assessments are likely to deal with benefits that are both undervalued (i.e. related to difficulties in quantifying the multiple value-dimensions of nature) and that accrue over the long-term (e.g. afforestation programs). As a result, ecosystem-based measures, such as those that that involve the conservation or reconstruction of natural lands, are likely to be afforded less priority than measures with more immediate and/or quantifiable costs and benefits (e.g. hard infrastructures or technological solutions). Furthermore, these types of feasibility criteria could also lead to land-use planning decisions that favour the use of natural lands (rather than other land types i.e. brownfields or existing urban lands) for development purposes, thus exasperating natural land degradation and the loss of key habitats and ecosystem services across regions.

The methodological approach adopted in Chapter 3, is based on the theoretical assertion that an equivalency can be adopted to equate in the present value of two identical pieces of natural land located in the same area. It posits that the mere act of granting permission for development on one of those lands leads to an immediate artificial increase in its value, which causes the two lands to be valued differently. The Equivalency Principle proposed by Chiabai et al. (2013), is an economic approach that calculates a discount rate at which the equivalency between the two lands can be regained. Contrary to other types of policy instruments used for environmental protection, such as an implementing an environmental tax or passing additional legislation, which can be highly political and time-consuming processes, one of the main advantages of the EP is that is can be easily integrated within land-use decisions. By using the EP, site-specific discount rates can be calculated and used immediately within feasibility assessments, and its application is theoretically valid under a limited set of assumptions.

While Chiabai et al. (2013) sets the theoretical foundations of the EP, Chapter 3 goes on to examine the feasibility of the EP for promoting natural land conservation across different land types and geographical regions. The approach adopted in Chapter 3 follows a version of the methodological process employed in Chapter 2. However, due to differences in studies accounting for natural land values, as well as difficulties in sourcing accurate market data on adjacent development sites with similar geographical and environmental characteristics, data collection methods involved a much broader articulation of search terms, more *ad hoc* search processes, as well as more loosely defined inclusion and exclusion criteria. Consequently, the results of Chapter 3 are intended mainly for illustrative purposes, to demonstrate the widespread viability of the EP for promoting land conservation efforts across different regions and land types. Further details on the methodological steps followed in Chapter 3 are provided in Appendix II.

The results of the systematic review of cost-benefit assessments conducted in Chapter 2, also sets a contextual basis for Chapter 4, which discusses the need for integrating certain extensions of CBA when valuing adaptation investments. Findings of the review show that most CBA of adaptation tends to focus on simplistic assessments of costs and benefits, with most valuations accounting for direct investment costs (i.e. capital, operation and maintenance costs) and the avoided monetary damages or savings related to measures. Less than half of the studies considered for the review include indirect costs or benefits, for example, related to the environmental, social and health effects of adaptations. As argued in Chapter 2, the limited consideration of these values within CBA is problematic, since assessments based solely on goods and services with market values or proxies will represent only a fraction of the total value of climate change and adaptation. Extra precaution must be taken when using profit maximisation techniques such as CBA especially when it comes to valuing public investments in adaptation. Public sectors have multiple economic, environmental, health and social objectives, and the improper consideration of these aspects within CBA can mean that many public needs may be ignored as a result.

The results of Chapter 2 point to two other interrelated areas of concern. The first relates to how CBA deals with climate change uncertainties and risks. Some studies apply climate change scenarios within CBA for dealing with various uncertainties and in extrapolating change that goes beyond past experience, but integrating scenarios is more easily done for some hazards (e.g. sea-level rise) than for others (e.g. drought), and these risks are still only considered in an acontextual manner. In much the same way, the aggregative focus of CBA means that it loses important contextual information, which could lead to decisions that reinforce underlying vulnerabilities within regions. For example, measuring welfare effects through estimates of willingness-to-pay means that protective programs are more likely to favour richer communities over poorer ones. The assumption that risks, costs and benefits are uniformly distributed across affected groups raises serious concerns about how CBA integrates issues of equity, rights and morality within assessments, given that failing to include these components does little to relieve, often times instead reinforcing, patterns of economic and social inequality.

CBA remains an important constituent of decision-making on adaptation, and until new economic decision tools better able to deal with the various unique dimensions of climate change become more prevalent, an important priority area of research in this field will be how best to adapt CBA for decision contexts involving climate change. Chapter 4 aims to explore various extensions of CBA, specifically in relation to employment, equity and risk, and how they can be used to improve public decision-making on adaptation. The approach uses a specific case-study of an adaptation project and conducts various cost-benefit analyses that consider employment, equity and risk factors under a set of core assumptions. An additional sensitivity analysis is also conducted to test how the efficiency of the adaptation project changes with adjustments in key parameters, such as the discount rate, the elasticity of income, and the extent of public risk aversion. Appendix III provides a more in-depth summary of the methodological steps followed in Chapter 4.

Phase II:

The studies conducted in Chapters 2, 3, and 4, highlight some of the methodological difficulties involved in valuing adaptation, and propose approaches for dealing with some of these issues. While refining and improving decision-tools such as CBA for adaptation can help to reduce uncertainties and better inform decision-makers, this does not necessarily translate into action. Adaptation involves other significant barriers to implementation, related to various technological, financial, behavioural, and social and cultural constraints (Adger et al., 2007). An emerging theme relates to the multiple actors involved in adaptation, and in understanding what drives their perceptions, valuation of risks, and what motivates them to take action. Empirical research from experimental economics strongly suggests that there is a great deal of heterogeneity in the time and risk preferences of individuals, and this in turn, affects proclivities to adapt (Bernedo and Ferraro, 2017). Studies from psychology have also shown that climate uncertainties, combined with individual and social perceptions of risks, experiences, opinions and values, can influence judgments and decisions related to climate change (Morton et al., 2011; Spence et al., 2011; van der Linden, 2015). It is becoming increasingly clear, therefore, that perceptions of climate change are context-specific, and that adaptation responses can be limited by human cognition.

Economists have studied decision-making over risk and uncertainty for some time now, with the central element of these theories focused on the idea that rationality is purely objective and analytical. Only recently, with insights from psychology, has there been a recognition that rational decisions may also be characterised by experiential factors, such as experiences, emotions, and moral intuitions. Despite an extensive literature that points to the influence of experiential factors in driving perceptions of risks and responses to climate change, very few studies directly investigate how experiential and analytical systems respond to risks and uncertain climate information, and even fewer studies explore these aspects in controlled or experimental settings. Experimental research can play a fundamental role in testing responses to risk information, which in turn can inform risk communication strategies for both autonomous and planned adaptation, as well as helping to identify cases where public policy interventions may be needed.

Chapters 5 and 6 use the tools of experimental economics to test some of the emerging theories on decision-making under risk and uncertainty. Both chapters follow a similar methodological approach, and combine techniques for elucidating risk preferences, testing experiential and cognitive forms of decision-making, and measuring adaptation responses in relation to different types of risk information formats. The approaches used in these last two chapters involved a significant amount of learning and research into how to develop, design and implement economic experiments. The actual organising and running of the experiments also involved new challenges, i.e. making sure they met ethical standards, and communicating and collaborating with programmers, recruitment companies and universities. In addition, I also had to build a core understanding of different types of statistical techniques and analyses that would enable me to interpret the experimental data with a certain level of rigour and accuracy. To facilitate this, I spent time learning R, a programming language for statistical computing and graphics, which helped immensely in handling, testing, and visualising large amounts of data. While the methodological approach in both chapters is similar, there are some core differences. The study presented in Chapter 5 is based on an artefactual sample (representative of the general population in

Bilbao), while that of Chapter 6 is based on a sample of students. In addition, because of the significant effects related to emotional factors in Chapter 5, a more comprehensive set of emotions was tested in Chapter 5. The study conducted in the Chapter 6 also includes a measure of the psychological and temporal distance of climate change and considers a wider range of experiential factors related to perceptions, feelings of efficacy, and sense of moral and personal responsibility towards climate change. Finally, due to speeding issues encountered for the risk elicitation approach in the first study, slight amendments were made to the programming of this task in the second study to avoid this issue from reoccurring[3]. A summary of the experimental approach employed in Chapters 5 and 6 is provided in Appendix IV.

1.3. Summary of key findings and insights

In this section, I highlight some of the key findings related to the research questions presented in Section 1.2.1, and how they connect to broader debates on the economics of climate change adaptation and decision-making in cities.

1.3.1. Economics and decision-making on adaptation are intricately linked

Setting the foundation for this thesis, the first research question seeks to explore how accurate the information derived from cost-benefit assessments on adaptation is, and to what extent it forms a credible basis for adaptation plans and investment decisions in this field (R1). We find a great degree of heterogeneity in the literature dealing with CBAs on adaptation at local levels, which makes drawing reliable conclusions on the costs and benefits of measures particularly difficult. There are several reasons for this, the first of which relates to the concept of adaptation itself. Adaptation is a broad theme that encompasses a variety of measures with diverse characteristics designed to deal with impacts stemming from very dissimilar types of natural hazards. As a result, economic assessments must deal with diverse aspects to do with, for example, cost-benefit considerations, assumptions, temporal and spatial scales, and future climate scenarios. The disparities between studies is exacerbated by the lack of comprehensive and universal guidelines for conducting cost-benefit assessments on adaptation, which means that important dimensions of adaptation and climate change, such as considerations of

[3] The risk elicitation approach used in the two experiments required participants to make five consecutive decisions between a lottery and a sure payment. While the lottery stayed the same in each of the decisions, the sure payment adjusted in subsequent decisions to be more risk-taking or risk-averse, depending on what participants previously selected. We observed that participants in the first experiment sped through this task, and many were unaware that they had to make five separate decisions. In order to avoid this from happening in the second experiment, we included a number slide in between each of the five decisions to emphasise that each decision was separate (i.e. first, second, third, fourth or fifth).

equity, intergenerational preferences, uncertainties and risk, are often mistreated or neglected. Moreover, due to non-market value dimensions that are difficult to quantify, ecosystem- or nature-based solutions may often be afforded less priority than other types of measures with clear market costs and benefits. These issues have significant implications for policymakers who seek to use cost-benefit information for developing effective adaptation strategies and plans.

As it stands, present-day adaptation approaches do little to relieve underlying vulnerabilities, in some cases even acting to intensify pre-existing social and economic inequalities[4]. Economic tools can improve upon cost-benefit analysis for decision-making on adaptation in a number of ways. Two such approaches are presented in Chapters 3 and 4. The first deals with how to adequately represent the value of nature within decision-making that involves the protection of natural lands. Ecosystems around the world are facing increasing pressures from climate change and ongoing urbanisation, and there is a critical need for decision-tools that promote conservation efforts. Decisions based on current discounting practices and valuation approaches will be ineffective at slowing rates of natural land degradation and ecosystem losses around the world, because they implicitly favour measures or land uses that are easier to monetise and that yield more immediate benefits. To address this, the second research question of this thesis explores the widespread viability of the Equivalency Principle across regions for encouraging the protection of diverse land types in land-use planning (R2). Our findings demonstrate that the EP can be successfully applied across regions for promoting the protection of different natural land types within land-use decisions. Across Europe, site specific discount rates between 0.3% and 1.1% were estimated, supporting the premise that discount rates should differ geographically on the basis of local specificities, such as societal preferences related to development and the environment.

The second approach for improving upon economic assessments of adaptation presented in Chapter 4, deals with how to consider employment effects, equity and risk-aversion within CBA, and assesses to what extent including these components affects decision outcomes (R3). Results suggest that the economic efficiency of adaptation investments is contingent on what types of considerations are included within CBA. Integrating elements of employment, equity and risk aversion can act to strengthen or weaken the case for action leading to higher or lower net-present values (NPV) and, depending on the discount rate, may even be the deciding factor for determining whether a particular action should be carried out or not (whether the NPV is positive or negative).

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[4] Determining the winners and losers of climate change and protective response measures is deeply contingent on what types of criteria are used within assessments, as well as what types of temporal and spatial scales are considered. Valuation approaches such as CBA, which focus on aggregate outcomes, are less sensitive to social and geographical variations. This means that, particularly when considering large temporal or spatial scales, the winners and losers of climate action may disappear within aggregate outcomes. Discourses centred around climate justice argue that the unequal distribution of resources and opportunities across populations and geographic space should be recognised within decision processes. By doing so, justice in society can be achieved by expanding opportunities and reducing pre-existing resource inequalities.

The results from Chapters 2, 3, and 4, demonstrate that decisions on adaptation will greatly depend on how economic assessments are carried out. Variations in factors such as discount rates, time horizons, implementation scales, future scenarios, and non-market considerations, make it difficult to compare cost-benefit estimations across measures and regions. The reliability of estimates is also made worse by the common disregard of aspects such employment, equity and risk within assessments, which could prove to be deciding factors of whether or not to implement certain measures. Addressing these disparities will help to reduce the uncertainties of decision-making on adaptation and lower the risk of maladaptation in the future. Developing more robust and universal frameworks for valuing adaptation will also help to better inform policymakers tasked with prioritising options within adaptation portfolios and mainstreaming adaptation into national political agendas.

1.3.2. Adaptation decisions depend on more than just monetary incentives

A growing body of evidence suggests that human behaviour is based on more than just a rational and mechanical response to price signals (Gowdy, 2008). Behavioural experiments have shown that financial incentives can actually lead to reductions in feelings of public responsibility, which can discourage the types of behaviours necessary for solving collective social problems such as climate change (Frey and Oberholzer-Gee, 1997). Thus, public policies on climate change will have to extend beyond traditional economic theory based on rational actor assumptions, and instead, can benefit from defining a broader incentive structure which recognises that human motivation is driven by far more than just prices.

The last two chapters of this thesis aim to investigate some of the behavioural dimensions of decision-making on adaptation, based on the premise that even if uncertainties related to the economics of climate change are reduced (i.e. as discussed in Section 1.3.1.), this will not necessarily drive increased motivations to act. Specifically, it investigates the cognitive and experiential effects of certain risk framings and experience, and the extent to which these influence investment decisions on adaptation (R4). Findings support those of previous studies which show a general perception of impacts as being psychologically distant in nature, which may lead to greater disengagement and reduced motivations to act on climate change. Presenting risk information in certain ways, however, can trigger different cognitive and experiential modes of information processing, which in turn, can alter investment behaviour on adaptation. In general, risk framings that target experiential factors related to, for example, positive and negative emotional responses, concern, previous experiences, and feelings of moral responsibility, can lead to more precautionary behavioural responses (higher investments in adaptation). However, given that experiential and cognitive systems compete when processing uncertain climate information, finding the right balance between these systems is necessary if risk communications are to evoke a certain level of analytical understanding whilst also being salient and motivating for target audiences. Results also highlight the importance of focusing on discrete emotions, since similar (positive or negative) emotions can have conflicting effects, acting to either amplify or depress the impact of risk framings.

These findings have significant implications for risk communicators, signalling a need to move away from dominant, technocratic approaches to risk that lack the experiential dimensions necessary for increasing issue engagement and connection, and motivating behavioural responses to climate change.

1.3.3. The usefulness of experimental approaches for eliciting preferences on adaptation and learning experiences

Experimental research has contributed significantly to the field of economics by establishing a strong empirical basis for testing traditional economic theory. While almost non-existent until the mid-1960s, economists have since increasingly turned to experimental economics as a means to better understand human behaviour and decision-making (Levitt and List, 2007). Experiments such as the Ultimatum Game and the Public Goods Game have helped to explain some of the many complex dimensions of behaviour, such as loss aversion, habituation, pure altruism, altruistic punishment, and hyperbolic discounting of the future (Gowdy, 2008). Despite some of the reservations surrounding lab-based experiments in particular, such as their ability to reflect "real world" decision contexts, a major benefit of labs relates to their ability to provide for controlled variation, a prerequisite for understanding causal relationships. Labs allow for a strict control of decision environments in ways that are difficult to duplicate in the field and are particularly useful for studying policy contexts that do not yet exist in the real world. Allowing the experimenter to control for factors such as material payoffs, the decision orders of different players, the information environment, and the frequency of decisions, are all important controls that permit a testing of specific economic theories and predictions (Falk and Heckman, 2009). Another benefit of labs is that they can also be used as complements to different data sources and empirical methods, i.e. field experiments.

Experimental economics is thus useful for focusing attention on how and why people make choices, for observing the actions of individual agents and the structural context within which they operate, for identifying patterns in those observed actions, and for predicting how and what choices might be made in the future. In the context of this thesis, the use of lab experiments was not only useful for controlling for key factors and variables, i.e. different audiences and types of demographics, but they also provided an environment for empirically testing some of the emerging theories on decision-making under risk and uncertainty, and specifically, in the anomalous context of climate change. The majority of previous social studies have used approaches such as surveys for understanding the main drivers of climate decision-making. But it becomes much more difficult to control for confounding effects within these approaches, and they tend to invite biases related to hypothetical responses (e.g. using a measure of willingness to act does not necessarily imply action in the real world). In fact, in terms of the latter, much of the previous literature on climate change risk communication draws a relationship between items such as risk, perceptions, concern, fear or worry and hypothetical behavioural or action responses (Cooper and Nisbet, 2016; Graham and Abrahamse, 2017; Hartmann et al., 2014; Mossler et al., 2017; Newman et al., 2012; Stevenson et al., 2014; Wiest et al., 2015), but as the findings from Chapter 6 show, neither risk perceptions nor concern among participants were strong predictors of observed investment behaviour during the second experiment. The results from the two experiments conducted in this thesis hope to add to the currently weak empirical evidence-base (Kellens et al., 2013) supporting the effects of different types of climate risk framings, and their impact on behaviour. Hopefully, the results from these empirical studies can also facilitate in building the necessary theoretical framework for identifying and selecting design features most conducive to effective risk communication on climate change.

1.4. Concluding remarks

This section will begin by discussing some of the limitations associated with the different studies that make up this thesis (section 1.4.1), before finishing with some potential avenues for future research (section 1.4.2).

1.4.1. Limitations

I will briefly touch upon some of the limitations of the research conducted in this thesis, but more detailed discussions on these can be found in the separate chapters. In general, two main limitations can be drawn from each of the methodological phases (I and II) of this thesis. The first phase, which relies predominantly on an exploration of previous studies as its main data source, depends greatly on the availability of, and accessibility to, different types of information. For studies that require extensive data gathering for conducting comparative assessments, i.e. such as in Chapters 2 and 3, analysis was constrained by a limit in the number of studies that were deemed relevant and reliable. As one would expect, the conclusions drawn within each of these studies would have been much more robust had analysis been conducted on greater amounts of data. This limitation can only be addressed over time once more data become available. The second methodological phase involved limitations primarily associated with experimental research. Indeed, many social scientists are apprehensive about conducting laboratory assessments due to aspects related to; small sample sizes, "unrealistic" contextual settings, trivial stakes, generalisability of results, inexperience of participants, and experimenter or researcher biases (Falk and Heckman, 2009). However, as discussed in section 1.3.3, despite these limitations there are significant benefits to laboratory experiments that are difficult to find in other empirical approaches; they provide controlled environments that permit the testing of causal relationships, they can reduce hypothetical biases, as well as control for important confounding effects. In addition, it is important to acknowledge that the evidence derived from experimental approaches are complements, not substitutes, to other data sources and empirical methods. Field data, survey data, and (both lab and field) experiments, in addition to traditional econometric methods can be used in combination to improve the state of knowledge in social sciences. There is no best approach when comparing these methods, and they all involve their own separate limitations.

1.4.2. Policy recommendations and avenues for future research

The findings presented in this thesis can help to inform adaptation decision-making and policy from different angles. In general, three broad areas emerge:

- Traditional economic approaches, such as CBA, in standard forms, are insufficient for dealing with the many anomalous aspects of climate change decision-making, i.e. the significantly large temporal and spatial scales associated with it. If these limitations are not adequately accounted for, decision-making on adaptation will continue to do little to relieve (and in some cases will exasperate) underlying social and economic vulnerabilities and can lead to maladaptation in the future. Decision makers can address some of the limitations of traditional economic valuation tools by looking beyond profit maximisation techniques, to include other important dimensions of investment decision-making related to, for example, distributional and non-market effects. In the case of CBA for example, various extensions can be used (i.e. related to risk, discounting, employment or equity), or it can complement other approaches such as adaptation pathways, robust decision-making and real-options analysis for promoting more transparent, fair and equitable investment decisions.
- As it stands, natural ecosystems around the world are under increasing threat from climate change, vast population growth, and ongoing urbanisation. For decisions involving land-use planning, tools such as the Equivalency Principle can be easily applied to feasibility assessments such as CBA, for promoting natural land conservation, integrating intergenerational preferences within decision-making, and limiting the potential for irreversible environmental losses (i.e. habitat destruction, loss of key species and biodiversity) in the future.
- There is currently a disparity between expert assessments of “risk statistics” and public perceptions of risks related to climate change. Relatedly, climate change is perceived as a psychologically distant issue, and many people lack a sense of personal connection and feel disengaged with the issue. In order to address this, climate change risk communication should move away from normative technocratic approaches to risk communication and aim to motivate

rational decision-making through communication devices that drive both analytical and experiential forms of risk information processing.

The studies presented in the various chapters also highlight several avenues for future research. In brief, some of the main emerging areas of interest are:

- To test the scope for other viable extensions of popular economic decision-tools such as CBA for the specific use in adaptation contexts, e.g. for measuring aspects related to non-probabilistic risks. Indeed, an increasing number of studies have highlighted the importance of considering "worse case" scenarios of climate change that can have potentially irreversible and catastrophic economic, social and environmental impacts (Abadie et al., 2017, 2016; Dietz et al., 2016a).
- Conduct comparative and critical assessments of emerging economic decision-tools that can be tailored for climate change contexts and decision-making, i.e. adaptation pathways, real-options analysis, multi-criteria approaches, and robust decision-making.
- Carry out comparative experimental assessments of risk communications and framings related to other types of climate-related hazards, i.e. heat waves, drought, and storm-events
- Conduct experimental assessments of other potentially significant behavioural and cognitive aspects and drivers of risky decision-making related to climate change, i.e. testing the effect of scientific and numerical literacy, previous knowledge on climate change, value systems and social norms on risk responses and behaviour.

Chapter 2: A critical review of cost-benefit analysis for climate change adaptation in cities

2.1. Introduction

While previous climate change adaptation research has centred predominantly around assessments of ecosystems and agriculture, of growing concern is the potentially devastating social and economic impacts of extreme weather events, such as floods, heat waves and droughts on cities. Cities are particularly susceptible to the impacts of climate change for a number of reasons. For one, because most cities are situated around coastal areas or close to riverbanks, they are highly vulnerable to the effects of sea-level rise and storm surge, affecting, or in some cases even displacing, large communities. In addition, the large extent of non-porous surfaces in cities makes it harder to deal with periods of high precipitation and river flooding, which can affect ecosystem services and critical infrastructures such as transport networks and social services. Cities are also prone to an urban heat island effect due to their high population densities and concentration of built infrastructure, which makes them significantly warmer than surrounding rural areas, causing increased health impacts and higher rates of morbidity and mortality, particularly among vulnerable or marginalized groups (Sainz de Murieta et al., 2014). These city impacts are of critical concern for policy discussions on climate change and adaptation not only due to growing urban populations (expected to reach 6.7 billion globally by 2050 from close to 4.2 billion today) (United Nations, 2018), but also because climate effects often act to amplify other social, environmental and economic drivers of risk (Revi et al., 2014).

Policy debates are now focusing much attention on how to help cities plan for adaptation, which requires detailed assessments of the costs and benefits of measures, as well as of the projected magnitude of impacts across diverse sectors and groups. Of special significance are cities in developing countries where much of predicted urban growth is expected to take place, and which often face an array of social, political and economic barriers to adaptation, such as equity concerns, infrastructure backlogs and severe financial and human resource constraints (Shi et al., 2016).

Cost-benefit analysis (CBA) is perhaps the most widely deployed tool for assessing the feasibility of both public and private adaptations to climate change. Its attractiveness stems predominantly from a common basis for comparison across projects, that is, an assessment of costs and benefits in monetary terms. This is especially beneficial for public sector decision-making in preventing inefficient spending of public money, in ensuring that regulatory costs are not inexplicably high or variable, and ensuring that resources are allocated effectively across diverse sectors and com- munities. CBA has also been argued to provide a more accountable, objective and transparent process for appraisal, since it requires all assumptions and uncertainties underlying decisions be revealed, and inputs to the analysis (e.g., expert judgements that may otherwise be difficult to comprehend) provided in a common and simplistic language that citizens are able to understand and contest. People naturally tend to consider budgets in everyday life, which makes the reading of cash flows in CBA familiar and easy to interpret.

Meta-analyses on adaptation have covered extensive ground thus far. Solecki et al. (2011), for example, investigate the links between disaster risk reduction and climate change adaptation in cities, and focus on three main areas of overlap related to event likelihood, impact parameters and societal responses. Carter (2011) conducts a qualitative appraisal of adaptation progress in European cities, and finds that policy frameworks and uncertainties related to climate science and institutional structures act as the main barriers to progress. In contrast, Reckien et al. (2017) provide an overview of the literature on climate change impacts, mitigation and adaptation in urban areas from an equity and environmental justice standpoint. Also noteworthy is Hunt and Watkiss's (2011) review of climate change impacts and adaptation in cities. While their review, including case studies from London and New York, is extensive, their work focuses on a synthesis of qualitative reports on adaptation, and quantitative assessments on climate impacts and risks. From an economic standpoint, Markandya and Watkiss's (2009) review of economic assessments on the costs and benefits of adaptation remains an important contribution. However, their appraisal is focused on global and national studies, with a small selection of case studies at the sub-national and local levels.

Evidently therefore the literature still lacks systematic urban scale analyses on the economics of adaptation, particularly one that investigates the full implications of cost- benefit analyses when it comes to adaptation research, as well as the diverse economic, social and environmental perspectives on its use. This is particularly relevant in light of recent criticism of existing IPCC assessments, which calls for more evidence-based reviews of adaptation practices whose findings are transparent, clearly defined and limit reviewer/author bias (Ford and Pearce, 2010; Petticrew and McCartney, 2011). CBA is a frequently applied instrument in the economic assessment of public policy across all sectors, and while its usefulness as a tool in the area of urban adaptation is clear, there are other equally important factors besides cost, such as equity, effects on the environment, health and society, and the physical effectiveness of protection, that also require attention. As it stands, empirical data on the costs and benefits of adaptation remain scattered. Evidence-led research can help improve upon adaptation science for governance, assisting in the prioritization of options and mainstreaming adaptation into local policy agendas. From these points a key research question arises, that is, how accurate is the information derived from CBA and, to what degree can it form a credible basis for adaptation plans and investment decisions in this field? This paper seeks to provide at least a partial answer to this question.

2.2. Methodology

Systematic review guidelines prescribed by Berrang-Ford et al. (2015) were used to evaluate recent cost-benefit analyses on adaptation in cities. In order to restrict the first phase of document selection to purely peer-reviewed works the Web of Knowledge (WoK) platform was used to scan articles under a set of broad search criteria so as to avoid excluding key literature sources. A keyword search was conducted on topic words (“economic valuation” OR “cost benefit analy*” OR “cost-benefit ratio*”) AND (adapt* AND drought OR flood* OR sea level rise OR coastal OR heat OR heat wave*). The search was restricted to include articles in the English language published between the years 2000 and 2017. 210 articles were selected for full-text review based on relevant titles and abstracts that fit the inclusion criteria (Table 2). The search criteria were intended to draw out relevant studies conducted on adaptation measures proposed for dealing with drought, pluvial and fluvial flooding, sea-level rise and heat waves in cities. These included infrastructural, technological, behavioural, institutional, financial and informational responses. Implementation scales from building level to the city level were considered, and studies were refined according to CBA employed in the widest sense in terms of maximizing or comparing welfare (Table 2). 22 articles which specifically fit the selection criteria presented in Table 2 were chosen for further analysis.

Previous research has highlighted the inadequacy of basing research synthesis of complex research questions solely on keyword searches (Greenhalgh and Peacock, 2005). In order to provide a more exhaustive scope for review, the “cited by” and “related articles” functions offered by Google Scholar were used on each of the 22 articles. Following the same screening approach of titles and abstracts, this extra search process yielded an additional 34 articles fitting the inclusion criteria, resulting in a total of 56 articles for final review. Information pertaining to each article was then summarised in an excel spreadsheet. This involved developing a set of qualitative and quantitative criteria for homogenizing and comparing the data through common metrics and terminologies. The objective here was to focus on prominent differences between studies related to uncertainties, impacts, scales, valuation methods and local dependencies. Standardization techniques were then used to make the data comparable — for quantitative elements this including converting all monetary values into 2016 International Dollars ($) using the consumer price and purchasing power conversion factors provided by the World Bank, and by converting size values into common units of measure (e.g., from hectares or acres to m2). For qualitative elements, generic terms were created to group the data into specific categories or concepts (i.e., whether scenarios considered “variable” or “extreme” climate changes).

Table 2. Identification, inclusion and exclusion criteria used in the literature search phase

Identification	
Study type	Published and peer-reviewed works
Source	Web of Knowledge and Google Scholar
Year or publication	Between 2000 and 2017
Inclusion	
Measure	All measures, i.e. structural, technological, institutional, economic, educational, behavioural, either autonomously or purposefully planned
Hazard	Drought, pluvial and fluvial flooding, sea-level rise, heat waves
Context	Implemented or planned for a city or urban setting
Assessment approach	Cost-benefit analysis or wider economic approaches assessing both costs and benefits in monetary terms
Implementation scale	All scales, i.e. individual/building-level to the city-level
Exclusion	
Costs and benefits	Does not detail both costs and benefits in monetary terms
Timescales & discount rates	Does not express the number of years the measure is valued for and whether a discount rate is applied
Region	Does not express where the adaptation is expected to take place

The final set included data on study aims, location, adaptation type and description, hazard type, temporal and spatial scales, scenarios, uncertainties, types of costs and benefits analysed, cost and benefit values, net-present values, benefit-cost ratios, discount rates, and currency units. Details of the studies considered in this review are shown in Table 3.

A further search was conducted on WoK to provide an insight into emerging economic tools (not derivatives of cost-benefit analysis) employed in adaptation assessments. A general framework based on new economic decision support tools for adaptation assessment identified by Watkiss et al. (2015) was used at this stage. These included approaches such as iterative risk management, real options analysis, robust decision making and portfolio analysis. This part of the study was conducted in order to explore the prevalence, strengths and weaknesses of alternative economic tools compared to cost-benefit analysis for adaptation assessments. Again, results were filtered according to articles published in the English language between the years 2000 and 2017, resulting in a total of 87 search results. After careful screening of relevant titles and abstracts, the final selection was refined to 36 articles on economic decision- support tools used for adaptation assessment.

Table 3. Literature reviewed of cost-benefit analyses of climate change adaptation in cities

No.	Reference	Hazard	Adaptation	Country
1	(Ossa-Moreno et al., 2017)	Pluvial flooding	Sustainable urban drainage systems	UK
2	(Coelho et al., 2016)	Sea-level rise	Revetments + beach nourishment	Portugal
3	(André et al., 2016)	Sea-level rise	Hard defences, beach nourishment + resettlement	France
4	(Frihy et al., 2016)	Sea-level rise	Hard defences + beach nourishment	Egypt
5	(Yazdi et al., 2016)	Flooding	Flood barriers, property level measures, detention dam	Iran
6	(Fletcher et al., 2016)	Sea-level rise	Seawall, property level measures, land-use changes	Australia
7	(Kono et al., 2016)	Sea-level rise	Levees	Japan
8	(King et al., 2016)	Sea-level rise	Seawall, beach nourishment	USA
9	(Martino and Amos, 2015)	Sea-level rise	Beach nourishment	Italy
10	(Sušnik et al., 2015)	Pluvial flooding	Sustainable urban drainage system	Netherlands
11	(Lu et al., 2014)	Sea-level rise	Seawall, land elevation	USA
12	(Kousky and Walls, 2014)	Flooding	Greenway (green infrastructure)	USA
13	(de Bruin et al., 2013)	Pluvial flooding + flooding	Rainwater harvesting, urban green areas, land elevation, property level measures	Netherlands
14	(Woodward et al., 2014)	Flooding	Levees	UK
15	(Dumenu, 2013)	Pluvial flooding + heat waves	Urban green areas	Ghana
16	(Penning-Rowsell et al., 2013)	Flooding	Flood storage, flood barriers	UK
17	(Zhou et al., 2013)	Pluvial flooding	Sustainable urban drainage system	Denmark
18	(Broekx et al., 2011)	Flooding	Flood barriers, dikes, floodplain conservation	Netherlands
19	(Peng and Jim, 2015)	Pluvial flooding + heat waves	Green roofs	Hong Kong
20	(Kontogianni et al., 2014)	Sea-level rise	Groins, beach nourishment, revetments and geotextiles, bulkheads	Greece
21	(Perini and Rosasco, 2013)	Heat waves	Green facades	Italy
22	(McPherson et al., 2005)	Pluvial flooding + heat waves	Urban green areas	USA
23	(Meyer et al., 2012)	Flooding	Dikes, resettlement, flood barriers, early warning system	Germany
24	(Woodward et al., 2011)	Sea-level rise	Seawall	UK
25	(Jianbing et al., 2010)	Pluvial flooding + drought	Rainwater harvesting	China

26	(Carter and Keeler, 2008)	Pluvial flooding + heat waves	Green roofs	USA
27	(Fairman et al., 2010)	Pluvial flooding + heat waves	Urban green areas	Australia
28	(Soares et al., 2011)	Pluvial flooding + heat waves	Urban green areas	Portugal
29	(Millward and Sabir, 2011)	Pluvial flooding + heat waves	Urban green areas	Canada
30	(Pothier and Millward, 2013)	Pluvial flooding + heat waves	Urban green areas	Canada
31	(Molinos-Senante et al., 2011)	Drought	Wastewater reuse & recycling	Spain
32	(Fan et al., 2015)	Drought	Wastewater reuse & recycling	China
33	(Molinos-Senante et al., 2013)	Drought	Wastewater reuse & recycling	Spain
34	(Liang and van Dijk, 2012)	Drought	Wastewater reuse & recycling	China
35	(Karim et al., 2015)	Pluvial flooding + drought	Rainwater harvesting	Bangladesh
36	(Liang and van Dijk, 2010)	Drought	Wastewater reuse & recycling	China
37	(Kirshen et al., 2012)	Sea-level rise	Beach nourishment	USA
38	(Kirshen et al., 2014)	Pluvial flooding	Sustainable urban drainage system	USA
39	(Mathew et al., 2012)	Pluvial flooding	Rainwater harvesting, sustainable urban drainage system, community preparedness and capacity building	India
40	(Wong et al., 2003)	Pluvial flooding + heat waves	Green roofs	Singapore
41	(Farreny et al., 2011)	Pluvial flooding + drought	Rainwater harvesting	Spain
42	(Blackhurst et al., 2010)	Pluvial flooding + heat waves	Green roofs	USA
43	(Chan and Chow, 2013)	Pluvial flooding + heat waves	Green roofs	Hong Kong
44	(Claus and Rousseau, 2012)	Pluvial flooding + heat waves	Green roofs	Belgium
45	(Godfrey et al., 2009)	Pluvial flooding + drought	Wastewater reuse & recycling	India
46	(McPherson, 2007)	Pluvial flooding + heat waves	Urban green areas	USA
47	(McPherson et al., 2016)	Pluvial flooding + heat waves	Urban green areas	USA
48	(Zhang et al., 2012)	Pluvial flooding + heat waves	Urban green areas	China
49	(Chen and Jim, 2008)	Pluvial flooding + heat waves	Urban green areas	China
50	(Zhou et al., 2012)	Pluvial flooding	Sustainable urban drainage system	Denmark
51	(Gocht et al., 2009)	Flooding	Early warning system	Austria, Spain
52	(Aevermann and Schmude, 2015)	Pluvial flooding + heat waves	Urban green areas	Germany
53	(Djukic et al., 2016)	Drought	Wastewater reuse & recycling	Serbia

54	(Jung et al., 2016)	Pluvial flooding + heat waves	Green roofs	South Korea
55	(Liu et al., 2016)	Pluvial flooding	Sustainable urban drainage systems	China
56	(McRae, 2016)	Pluvial flooding + heat waves	Green roofs	USA

2.3. Results and discussion

2.3.1. Types of adaptation

Drought

The adaptation literature on drought in cities is limited to supply-side measures of rainwater harvesting systems and wastewater reuse and recycling systems with implementation scales ranging from the building/infrastructure to the city level. The limited coverage of drought measures in the literature is in line with previous research which cites inadequate information on the costs and benefits of impacts and measures as a major obstacle to the implementation of drought mitigation and adaptation strategies (Brenner, 1997). Many of the problems underlying cost-benefit analysis on drought stem from the challenge of quantifying a slow progression of impacts that are neither highly visible nor structural, which also means that few studies are conducted systematically. Studies on rainwater harvesting yield better consideration of benefits (i.e., in terms of avoided impacts) since they are also used as an adaptation to flooding. Therefore, avoided costs related to flood damage are commonly included in benefit appraisals for this technology (de Bruin et al., 2013; Jianbing et al., 2010; Mathew et al., 2012). Assessments on wastewater reuse and recycling on the other hand, are much more sporadic. Most studies consider both financial benefits (i.e., in terms of revenues from the sale of regenerated water and/or cost savings on fertilizers) and environmental benefits of avoided water pollution (Djukic et al., 2016; Fan et al., 2015; Molinos-Senante et al., 2013, 2011). Other benefits assessed include: avoided health care costs, increase of water availability (Godfrey et al., 2009; Liang and van Dijk, 2012, 2010), residential resettlement, increase of jobs (Liang and van Dijk, 2012, 2010), avoided overexploitation of groundwater, reuse of pollutants and avoided odour abatement costs (Godfrey et al., 2009). The drought measures identified in this review relate to measures able to deal with long-term issues of warmer temperatures and water scarcity caused by climate change. Cost-benefit analysis of measures that deal with droughts as short-lived events are not as prevalent in the literature. Short- term measures might involve, for example, agricultural irrigation management and other forms of rationing (e.g., limiting water-use to specific cash crops and irrigation scheduling), administering public aid to critically affected areas, and distributing short-term financial measures for helping farmers cope with reduced incomes caused by lowered crop yields (Dziegielewski, 2003).

Pluvial and fluvial flooding

Proposed adaptations for flooding in cities include: social measures such as community preparedness and capacity building, climate proofing houses, early warning systems and resettlement of flood prone communities; hard infrastructure measures such as watershed management, construction of dikes, levees and flood barriers, land elevation and spatial planning, urban drainage systems and rainwater harvesting systems; and "green" measures such as floodplain conservation, green roofs, and other green infrastructures such as greenways and urban green areas.

Assessments of pluvial and fluvial flooding make up 66% of the total number of studies considered in the review. The prevalence of appraisals to do with inland flooding is unsurprising. When assessing the impacts of climate change on global river flood risk, Arnell and Gosling (2016) find that in 2050, what is today considered a 100-year flood event, would be twice as frequent across 40% of the globe, affecting around 450 million people in flood-prone areas and 430,000 km2 of cropland worldwide. The wide range of measures besides hard approaches represented here also supports previous assertions that traditional engineering methods alone will unlikely be able to provide adequate levels of protection in the future (Ashley et al., 2005).

Sea-level rise and storm-surge

Measures for adapting to sea-level rise and extreme storm events (causing coastal flooding or beach erosion) include: soft adaptations such as beach nourishment, re-settlement of affected communities and changes in building regulations, and hard adaptations such as construction of bulkheads, groins, levees, revetments, sea walls, and land elevation and spatial planning. Strategies are also being designed that com- bine both hard and soft measures, such as: the construction of hard defences (i.e., seawalls), beach nourishment and the use of revetments with geotextiles. Certainly, the integration of hard and soft approaches is useful for gaining the benefits of both the flexibility of hard approaches (e.g., raising wall levels) with the reversibility of soft approaches, which makes them better suited for dealing with high levels of future uncertainty (Hallegatte, 2009).

Heat waves

The literature on adaptation to heat waves in cities only covers green measures, such as green facades, green roofs and urban green areas. The attractiveness of these green themes lies in their potential to artificially reverse the effect of the urban heat island effect in urban areas by replacing impervious built surfaces with previously lost vegetative cover. These types of adaptations provide a host of benefits such as cool shading, evaporative cooling, rainwater interception and storage, air pollution removal, habitat creation and biodiversity, as well as aesthetic and recreational values. Indeed, as Carter (2011, p. 195) notes: "strategies and actions developed exclusively to promote adaptation goals are unlikely to be as effective as measures that integrate adaptation alongside the progression of other agendas, such as climate change mitigation, health and wellbeing, or enhancing the economic competitiveness of cities". The systemic literature search adopted in this study was unable to identify measures for dealing with heat waves as temporary, short-lived events. Such measures might include installing air-conditioning or cooling systems in building and transport infrastructures, establishing emergency relief centres, early warning systems, property-level measures (e.g., external window shutters and painting external walls or roofs a lighter colour) and informational campaigns for citizens on how to manage heat stresses (Zuo et al., 2015).

2.3.2. Contextual settings

The literature covers a total of 24 countries across Europe, Asia, North America, the Middle East and North Africa, Australia and West Africa. Although these findings are generally consistent with the distribution of adaptation efforts observed worldwide, the limited coverage of adaptation in African regions (Fig. 3) is surprising given that between 2006 and 2009 the second-most number of activities on adaptation were reported to take place in Africa (Berrang-Ford et al., 2011). This disparity points to the challenges of conducting economic assessments of adaptation in developing countries. Certainly cost-benefit analysis is often financially and human-resource intensive, time consuming and requires considerable expertise (Ackerman and Heinzerling, 2001), which restricts its application in certain regions. On top of this, CBA for adaptation faces considerable criticism, particularly from developing nations, in the way it quantifies non-market values, especially through estimates of willingness to pay (WTP). For one, the notion of WTP raises concerns over considerations of distributional equity. Since the rich are more able and more willing, to pay more for environmental protection, this means that protective programs are likely to favour richer communities over poorer ones. Secondly, CBA tends to consider risk in an "acontextual" manner — that is, it tends to ignore important contextual information, for example, on patterns of economic and social inequality. Thus, CBA fails to adequately integrate issues of equity, rights and morality that cannot be reduced to monetary worth, making its application in developing regions challenging and its consideration of different income groups within regions problematic.

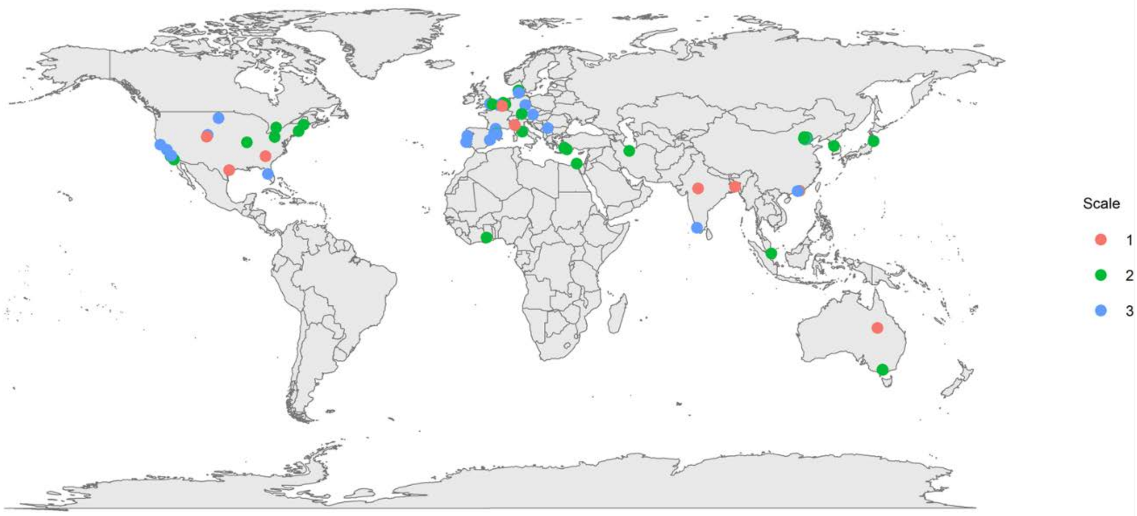

Figure 3. Distribution of adaptations at various scales of implementation covered in the literature

Note: 1=building/infrastructure level, 2=district/neighbourhood level, 3=city/regional level

Affordability plays a major role in how we value non-market items, and researchers have been gravely concerned for some time now with how to consider these valuations within CBA in a fair and equitable manner. Alternatives such as Willingness to Accept (WTA), which measures the amount a person is willing to accept as compensation, i.e., for environmental degradation or to forgo environmental benefits, have since been proposed. But large disparities between WTP and WTA estimates have alluded to other equally problematic factors. While the amount one is willing to pay for (or to avoid) something is constrained by the limits of his or her budget, the sum one might be willing to accept as compensation for something could be infinite. The nature of WTA means that an individual's actual loss cannot be separated from what they believe their loss to be. This essentially gives every loser the power of veto, since the efficiency outcome of CBA can be swayed by one infinitesimal value. When using WTA, economists often exclude stated values that are extreme as "outliers" and not consistent with the concept of rational decision-making. But imposing limits on WTA means not fully accounting for the true concerns and preferences of people, and by implicitly suggesting that — those who believe that some things are priceless – are irrational, CBA risks losing its political authority as well as its moral legitimacy (Adams, 1993). Recent work in this area has demonstrated that with careful survey design and use in appropriate contexts, WTA can be elicited without much bias and extreme values. As a result, a number of researchers recommend using WTA rather than WTP when losses are being valued (Lloyd-Smith and Adamowicz, 2018; Villanueva et al., 2017; Whittington et al., 2017).

Perhaps more promising is an approach that incorporates equity concerns directly into CBA, whereby the effect on incomes of different societal groups (the distribution effect) is considered alongside the effect on resource allocation (the efficiency effect). One way to do this would be to assign distributional weights to reflect the relative incomes of those people receiving the benefits or bearing the costs of an investment. By using this approach, those with lower incomes can be assigned greater weights to increase their relative importance within decision-making. This method dates back to the 1960s when Weisbrod (1968) began stressing the importance of distributional impacts to policy-makers. Despite its inclusion in cost-benefit manuals during that time, its use within CBA ceased in subsequent years with decreasing concerns over income distributions although interest in it has re-emerged recently in guidelines on Cost Benefit Analysis (Treasury, 2018). The dominance of private, building or neighbourhood level adaptations such as rainwater harvesting systems, green roofs, green facades, urban green areas, and property-level measures against flooding in primarily richer states (Fig. 3), also alludes to the predisposition of private individuals or groups in wealthier regions to invest in adaptation. This raises questions as to how economic frameworks such as CBA can ensure equitable distribution of decision-making power and benefits of action across diverse contexts. Engaging community or social advocacy groups within policy dialogues on adaptation would ensure greater representation of minority voices and needs, however some authors have signalled a post-political shift[5] in urban governance when it comes to decision-making on climate change (Chu et al., 2018). The little attention granted to dimensions of equity, inclusiveness and justice within climate policy development not only makes it difficult to address specific needs of disadvantaged groups, but also limits the potential for adaptation to be systematically mainstreamed into local development and management policies (Shi et al., 2016).

The matter of ensuring equitable adaptation processes is one that concerns decision- makers at all levels of governance. Adaptation is a broad term extending across various sectors, locations, scales and actors. This makes defining the exact roles and responsibilities of citizens, communities, corporations, public and private organizations, governments and international institutions challenging. There is a great need to better understand the current opportunities and constraints of adaptation within diverse contexts and at various levels of decision-making with the aim of reducing overall vulnerability and enhancing adaptive capacity. From a global perspective, this might require an investigation into the current state of institutions and infrastructures, and access to capital, technology and information across nations. At a local-level, it means identifying especially vulnerable groups and demographics, communities reliant on climate resources, specific areas of social and cultural conflict, and the need for civil society for mediating between policy-makers and the public. Improving upon this knowledge will help those with power and access to resources at local, national or international levels ensure that vulnerable nations, sectors and communities have access to those critical economic, social and informational resources for building capacity and resilience in the face of climate change. One can see such data and its analysis as complementary to that used in any benefit cost analysis and would enrich it greatly (see Sec. 2.3.4).

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[5] Post-politics in this context refers to the critique, by urban geographers and sociologists, of increasingly non- traditional and apolitical forms of urban governance largely reliant on aspects such as scientific expertise, bureaucracy and epistemic knowledge. Critics argue that the lack of negotiation and discussion on different urban interests may result in (often neoliberal) governance outcomes that lead to the disenfranchisement of minority voices and needs (Chu et al., 2018).

2.3.3. Time horizons and climate change scenarios

Figure 4 presents the range of time scales and discount rates adopted in cost-benefit analyses on adaptation. The figure clearly shows that the bulk of appraisals favour short to medium time horizons, i.e., between 1 and 50 years (80%), with few extending past 60 years. These short time frames tend to reflect the lifecycles of green infrastructures (i.e., green roofs and green facades) and technological adaptations (i.e., rainwater harvesting and wastewater reuse systems), which commonly last between 30 to 50 years, and 10 to 30 years, respectively. There are several potential reasons for the consideration of short-term time periods within adaptation assessments. Firstly, decision-making on adaptation must be made within certain political horizons, wherein policy-makers often struggle to balance the long-term need for sustainable development against the short-term need for economic and policy development. When resources are scarce, short-term interests tend to prevail and it becomes harder to persuade stakeholders to make long-term provisions for adaptation that might have few immediate gains. Secondly, continuing climate shocks in the form of extreme events that reduce the coping capacity of regions, may cause them to seek immediate risk- management strategies before considering longer-term solutions to future and more gradual climate changes. But the reliance on reactive responses runs the risk of rein- forcing short-term strategies at the expense of long-term precautionary adaptations. This in turn may limit the capacity of regions to reduce vulnerability and improve resilience to future, potentially more severe, climate risks. Where adaptation is incremental, policies should aim to adopt strategies of adaptive management, whereby short-term actions are reassessed as new information about future impacts comes to light. Adaptation interventions that are able to address both short-term economic un- certainty and climate vulnerability as well as long-term strategic objectives to reduce climate risk are likely to maximize the probability of achieving sustained benefits in the future (Burton et al., 2005). In contrast, longer time scales, greater than 50 years, tend to be associated with hard infrastructures for dealing with inland and coastal flooding such as urban drainage systems, land elevation, and hard defences, such as dikes, groins and sea walls. Explaining this are the various scenarios of sea-level rise and future damages frequently adopted in these appraisals, which require long term assessments of risk and vulnerability. The uncertainties underpinning future sea-level changes, however, have resulted in highly variable scenarios of sea-level rise.

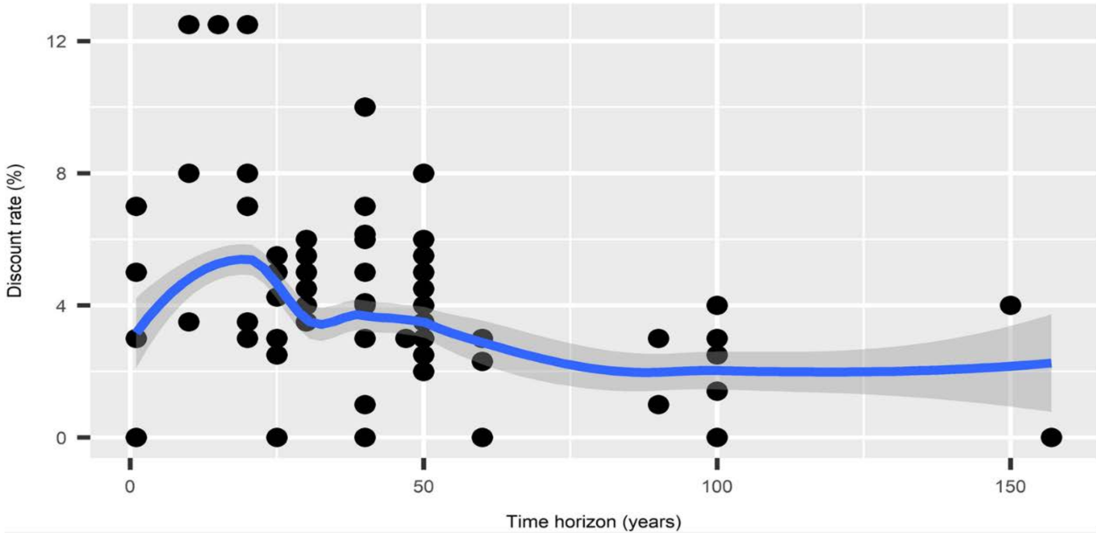

Figure 4. Time horizons and discount rates considered by the literature

Taking the US as an example, Kirshen et al. (2012) calculate coastal impacts for Maine based on low (0.1 m by 2030 and 0.17 m by 2050) and high (0.22 m by 2030 and 0.37 m by 2050) SLR estimates taken from Rahmstorf (2007). For Florida, Lu et al. (2014) base their SLR projections on the Federal Highway Administration (2010) estimates of 0.3 m (in the next 50 years) and 0.6 m (in the next 100 years) for the Gulf of Mexico. While for the West coast, King et al. (2016) calculate the impacts of SLR in California based on three scenarios of 1 m (Cayan B1), 1.4 m (Cayan A2)[6] and 2 m (Pfeffer et al., 2008) by the year 2100. SLR scenarios for the UK are similarly varied. For London, Penning- Rowsell et al. (2013) consider a rise in sea-levels of just over 1 m by 2105 (based on DEFRA06 recommendations), while Woodward et al. (2011) use the more conservative low (0.28 m), medium (0.345 m) and high (0.425 m) climate change scenarios for 2100 taken from the UKCP09 climate change projections for the UK.

The consideration of "worse case" SLR scenarios applied across regions highlights the increasing attention being placed on potentially catastrophic impacts, with several of the aforementioned studies considering ranges in line with, or extending past, the RCP 6.0 (0.33–0.63 m by 2100) and RCP 8.5 (0.45–0.0.82 m by 2100) estimates provided by the latest IPCC Fifth Assessment Report. Taking a risk-averse stance when planning for adaptation seems practical, especially in light of recent studies show-casing the devastating impacts of low-probability, high-impact climate change events. Based on probability distribution functions of future SLR for 120 coastal cities under RCP 2.6, 4.5 and 8.5 scenarios, Abadie et al. (2016) estimate economic losses caused by low-probability high-impact events to be between 139% and 746% higher than mean expected values. Similarly, when considering the

[6] These findings are taken from Cayan et al. (2008)

impacts of 21st century climate change on global financial assets, Dietz et al. (2016a) find that while "climate value at risk" (VaR) amounts to around 1.8%, or $2.5 trillion, under a business-as-usual emissions path, much of the risk lies in the tail with VaR estimated at 16.9%, or $24.2 trillion, in the 99th percentile. These findings have important implications for policymakers and investors, who must decide not just how much they can afford to spend, but how much they can afford to risk when it comes to climate change.

The application of climate change scenario ranges is an important addition to CBA, which has long been criticized for its limited ability to account for the magnitude of climate change uncertainties and in extrapolating change that goes far beyond past experience. Indeed, CBA tends to typically incorporate climate change through probabilistic risks. As Table 4 shows, most cost-benefit analyses use simplistic approaches for dealing with uncertainty, for example through sensitivity analyses (of discount rates, time horizons, implementation scales, etc.) and benefit-to-cost (BCR) ranges. Few studies consider the timing and type of investments based on future information, or actually report the robustness of the BCR with respect to parameters that are uncertain or for which no probability distributions exist.

Table 4. Uncertainty considerations within cost-benefit analyses of adaptation

		No. of studies	% of total
Carry out a sensitivity analysis with respect to:	Benefits	33	58%
	Costs	30	53%
Report the final BCR as a single value or range	Single value	21	37%
	Range	35	61%
Report the robustness of the BCR with respect to parameters that are uncertain and for which no probability distributions are available	Yes	5	9%
	No	51	89%
Attach a monetary risk premium for the uncertainty attached to the benefits to reflect risk aversion	Yes	2	4%
	No	54	95%
Consider the timing and type of investments based on possible future information?	Yes	10	18%
	No	46	81%

New economic decision-making tools, that can be used independently or as extensions of CBA, have emerged over recent years to address these challenges (Fig. 5). These include, for example, adaptation pathways, robust decision-making and real-options analysis, which have been designed for the development of flexible adaptation plans that can be tailored to specific contexts or adjusted in light of new information or future changes in the environment (Buurman and Babovic, 2016). Such approaches are rare as it stands, and their potential for more widespread application is yet to be established.

2.3.4. Discount rates and non-market costs and benefits

Environmental economists have stressed the importance of using near-zero discount rates, primarily as an ethical and immediate responsibility towards future generations, but also for encouraging more effective and progressive policy design (Stern, 2007). It is interesting, therefore, that so few studies (12.5%) actually employ rates below 2%, that so many (30%) use rates of 5% or higher, and that only two studies consider declining rates (Woodward et al., 2014, 2011).

Certainly, the often long time scales associated with climate change imply that conventional discounting practices, i.e., based on market rates, are inadequate for valuing residual costs and the benefits of avoiding future climate impacts. The higher the rate the more rapid the decline in the value of costs and benefits over time, making it harder to account for future risks that are not probabilistic, i.e., extreme or irreversible events. The use of market rates also raises ethical concerns as to whether it is right to discount non-market values such as lives saved, health and wellbeing, species preservation, the welfare of future generations, biodiversity and nature, in the same way we do financial returns. What makes this particularly problematic is that there are likely to be considerable monetary, environmental, social and health benefits of protective action, which are expected to occur in the distant, rather than immediate, future. The most logical argument in favour of discounting is that we would expect as people get wealthier over time they will be able to spend more to save their lives and to preserve the environment. The fundamental problem with this idea lies in the fact that the environmental problems we are facing will extend far into the future, meaning that the decisions we make today will not only impact ourselves but also those who come after us, in some cases irreversibly. Indeed, climate research has been warning us of the potential for catastrophic and irreversible environmental losses such as the melting of polar ice caps, the destruction of coral reefs, ocean acidification, increased coastal flooding and erosion due to rising sea-levels, species extinction, and the growing impact on crop production and migration in certain parts of the world. As shown in the previous section (with 80% of studies favouring short-medium timescales), programs designed for the near term are often considered more desirable than programs designed for the long-term, giving priority to immediate economic gains over, for example, the environmental, health or social outcomes of projects.

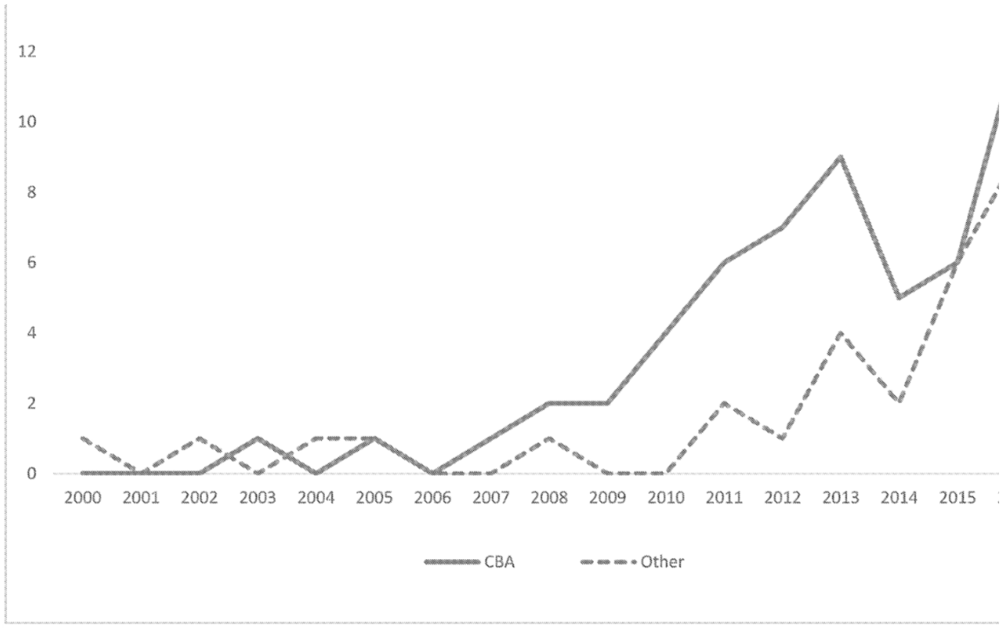

Figure 5. Time series of cost-benefit analysis against other emerging economic tools for valuing adaptation

As it stands, only 34% of studies consider the indirect costs of adaptation and only 54%, 46% and 13% consider the environmental, social and health benefits of adaptation, respectively. The latter is particularly surprising, given the potential magnitude of climate change impacts on health. Taking Europe as an example, climate change is expected to cause growing thermal stresses due to heat waves, increases in diseases related to air pollution, increases in mortality and morbidity due to extreme events and flooding, excess cases of Lyme disease and tick-born encephalitis, and increases in leishmaniosis in Mediterranean regions (Markandya and Chiabai, 2009). In terms of economic impacts, Kovats et al. (2011) find that climate change induced health costs across Europe, related to heat and salmonellosis, could range anywhere between €46 billion and €147 billion by the year 2080. In a study on the projected economic impacts of climate change in sectors of the European Union (EU) based on bottom-up analysis, Watkiss et al. (2009) estimate that under a projected warming of 3.9°C by the year 2100, the additional heat-related deaths for 27 EU member countries will near 107,000 annually during 2071–2100. By the year 2080, the authors estimate that the costs associated with these deaths could range from €50 billion annually, when valuing each excess death, to €118 billion, when valuing the loss of a year of life. Ex-post studies showing actual impacts of specific climate events are also rife. Hunt et al. (2007) calculate the cost of the 2003 summer heat wave in the UK which resulted in 2157 deaths and an excess of 1650 hospital admissions, to be approximately £41 million (with a cost range between £14 million and £2.6 billion[7] depending on whether a value of life year or value of a prevented fatality is

[7] This is equivalent to an average of €52 million (with a cost range between €18 million and €3.3 billion) in 2018 prices using the Purchasing Power Parities and Consumer Price Indices provided by the OECD databank: https://data.oecd.org/.

used). A complete synthesis of European studies can be found in Hutton and Menne (2014), who examine the economic evidence on climate change health impacts and adaptation across 53 countries of the World Health Organisation (WHO) European Region. For worldwide estimates, Markandya and Chiabai (2009) examine the health impacts of climate change by region, and provide a cost-effectiveness index for alternative health adaptation interventions based on estimates of total costs from the literature.

As evidenced above, using CBA to value health adaptation programmes can be challenging because it implies introducing savings or losses in terms of affected lives. This means either estimating the value of life itself or placing a value on each year of life saved or lost. The methods developed to measure life have resulted in considerable debate and disparities between study estimates. While some choose to value life differently for different countries (more or less relative to real per capita GDP), others choose to apply the same value to all lives irrespective of country or context. The use of country-specific values for life has caused political tension in the past, since lower values of life tend to be ascribed to developing regions (Viscusi and Aldy, 2003). Taking a study on wastewater reuse in residential schools in Madhya Pradesh as an example, Godfrey et al. (2009) calculate that the value of loss-of-life[8] based on the discounted productive years lost (21.9 years), the age standard mortality rate (150 per 100,000) and the opportunity cost per year of life lost (INR 30,000 per year), amounts to a value of $70,912[9] for each life lost. If we were to conduct this study in the UK by comparison, then the value of loss-of-life (using the same valuation method) would amount to approximately $470,000 for each life lost.[10]

Issues arise from both approaches, making the consideration of health impacts within CBA problematic. In spite of these challenges, health impacts are likely to represent significant values in the context of climate change and adaptation, making their disregard within CBA unjustifiable. The same holds true for the evaluation of environmental and social impacts. The Stern Review (2007) calculates that with a 2○C warming, around 15–40% of land species could face extinction, with most major species groups, biodiversity hotspots and vast areas of tundra and forest affected. Additionally, we can expect to see coral bleaching in many areas beyond recovery, affecting tens of millions of people that rely on coral reefs for their livelihood and food supply. At this rate of warming, resources affected by climate change may drop below a critical threshold, forcing many communities to migrate, and spurring further economic, social and cultural divides that reinforce existing inequalities.

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[8] This was calculated as a benefit of wastewater reuse and recycling systems – estimated from the avoided deaths occurring from diarrhoea due to water contamination

[9] Calculated in 2016 USD using the CPI and PPP provided by the World Bank databank

[10] This calculation was based on the UK minimum wage rate of GBP 7.38/hour, assuming 170 hours per month (https://www.gov.uk/minimum-wage-different-types-work/paid-an-annual-salary) and converted to USD using current exchange rates

The limited consideration of these values within CBA is problematic, since assessments based solely on goods and services with market values or proxies will encompass only a fraction of the total value of climate change and adaptation. In practice, public sectors have multiple (economic, environmental, health and social) objectives, and applying profit maximization techniques such as CBA means that many public needs may be ignored as a result. Of course, integrating such values into CBA is incredibly challenging. Differences in valuation methods are known to heavily impact outcomes and emerging research has shown that different valuation methods are needed for eliciting diverse value-types, all of which still have blind spots (Jacobs et al., 2018). International bodies such as the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) have encouraged the use of "integrated valuation" when it comes to the environment. This approach aims to capture three main value-dimensions, non-anthropocentric, relational and instrumental values, through diverse (socio-cultural, biophysical, monetary and synthesizing valuation) methods.

As Jacobs et al. (2018) assert, while single-value methods might seem more cost-efficient, they have a reduced capacity to provide information about multiple values that could have risky implications for decision-making in human-nature con- texts making them inefficient and ineffective. Assessing the suitability of 21 valuation methods for 11 value-types, the authors find that integrated valuation can be achieved by using a set of complimentary methods, and without spending excessive resources. While this approach is still new and there are no CBA studies that adopt it, it represents a promising effort to capture a more holistic value of nature's contribution to people.

2.3.5. Benefit-cost ratios

A breakdown of benefit-cost for each adaptation measure and their relative ranking disaggregated by climate hazard is shown in Table 5. It should be noted at the outset that most of these values represent ex ante estimates of benefits and costs. To date ex post estimates of BCRs are scarce as virtually all projects have not completed implementation. Of course, short-term responses to stochastic events such as storms, heat waves or droughts will have already happened, but not all of these measures will have been labelled as an adaptation to climate change. This important gap will only be filled over time. It is also worth mentioning that the BCR of adaptation options seems to be greatly influenced by aspects such as the choice of discount rate, time horizons, implementation scale, and the consideration of certain costs and benefits. As it stands, the current sample size does not permit a complete understanding of whether these factors are specific to certain hazards or measures. Differences in these critical parameters make it difficult to draw comparisons between studies when it comes to their efficiency. For these reasons, the BCR estimates for these solutions are tentative and the results presented in this section are intended for illustrative purposes. Adaptations that are considered very effective, effective and ineffective are discussed below. These classifications are based solely on a simplistic evaluation of lower-, middle- and upper-bound estimates of BCRs as well as their relative rankings within hazard types, the standard deviation and variance for each measure should be taken into account.

Very effective measures

Soft defences, namely artificial nourishment of beaches, appear to be among the most effective measures for dealing with the impacts of sea-level rise and storm surges. The higher ranking of these measures compared to a combination of hard and soft approaches and hard defences alone could be attributed to their lesser impact (or perceived impact) on the environmental and on the social values of beach sites. Whilst often considered places of ecological and environmental importance, beaches also tend to be recognized for the high touristic, recreational, and aesthetic benefits that they accrue. Despite the potentially large environmental and social benefits associated with soft measures, the literature seems to place greater attention on the valuation of hard defences for sea-level rise and extreme storm events. This could be due to the fact that hard engineering options for adaptation are easier to cost and are subsequently preferred or given greater priority within decision-making processes compared to soft or behavioural alternatives (Markandya and Watkiss, 2009). But the inherent bias toward harder options might adversely affect critical soft approaches with important innovative and technological components (Markandya and Galarraga, 2011). In fact, less than 25% of hard infrastructure assessments actually consider costs and benefits of adaptation beyond those internalized by the market. These may include social effects such as impacts on well-being, recreation and aesthetic values, or environmental effects such as impacts on habitats, biodiversity and ecosystem services. This calls into question the sustainability of hard adaptations, moving beyond direct costs toward more holistic assessments of the values associated with these measures will help to address this issue.

Effective measures

Although less studied, behavioural options such as community preparedness, early warning systems and property-level measures, also stand out as effective adaptation responses. The positive performance of these adaptations is likely linked to their low costs (e.g., related to training vulnerable communities for emergency management, establishing climate-sensitive building regulations and designs, and encouraging households to climate-proof homes), as well as their effectiveness in engaging and empowering individuals to take action on climate change for themselves. This shift in decision-making power from policy-makers to the individual, so-called "governing by enabling", not only facilitates awareness-raising of climate change issues, but also motivates positive behavioural changes among decision-makers and affected stakeholder groups (Carter, 2011), The long-term sustainability of these options will rely on building human and institutional capacity for adaptation and enabling direct engagement with local governments, which can accelerate implementation rates and improve upon urban adaptation outcomes (Revi et al., 2014).

Table 5. Benefit-cost ratios, ranks, standard deviation and variance in measures disaggregated by hazard type

Measure/Hazard	BCR (mean)	Rank	σ	S^2	No. of Studies*
Drought					
Rainwater harvesting	1.37	2	1.22	1.5	4 (66)
Wastewater reuse and recycling	1.98	1	2.75	7.6	8 (49)
Pluvial flooding					
Rainwater harvesting	1.37	5	1.22	1.5	4 (66)
SuDS	1.80	4	1.53	2.3	7 (37)
Community preparedness	30.49	1	5.89	34.7	1 (4)
Property level measures	7.81	2	16.11	259.7	3 (14)
Green measures	2.25	3	8.83	78.0	20 (95)
Fluvial flooding					
Hard and soft defences	1.47	2	0.61	0.4	1 (4)
Green measures	1.42	3	0.29	0.1	1 (3)
Hard defences	0.50	4	0.23	0.1	1 (6)
Early warning systems	4.31	1	5.46	29.8	2 (5)
Heat waves					
Green measures	2.25	-	8.83	78.0	20 (95)
Sea-level rise					
Hard defences	40.45	3	108.11	11687.5	10 (98)
Hard and soft defences	82.91	2	163.28	26658.8	5 (19)
Resettlement	1.82	5	2.33	5.4	2 (11)
Soft defences	110.98	1	189.07	35746.03	4 (25)
Property level measures	8.21	4	16.70	278.84	2 (13)

Note: *Values in parentheses represent the count used for statistical summaries. This is due to, for example, the testing of multiple climate scenarios, implementation scales, discount rates etc. which may result in a range of values for each study

Green measures, such as building urban parks, greening the sides of buildings and roofs, conserving floodplains, and establishing climate-robust ecological networks, are not found to rank especially high compared to their alternatives for heat waves and flooding in cities. This result is particularly surprising when considering the many positive health effects linked to green spaces and infrastructures, which include: in- creased life expectancy of senior citizens' (Takano et al., 2002; Tanaka et al., 1996), increased activity levels and perceptions of health and relaxation (Korpela et al., 2001; Payne et al., 1998), decreased levels of stress and anxiety (Ulrich et al., 1991), improved concentration and attention levels (Hartig et al., 1991; Taylor et al., 2001; Wells, 2000), lowered blood pressure levels (Hartig et al., 2003), and reduced mental fatigue (Kuo and Sullivan, 2001). Limits in valuation approaches for non-market items might explain this finding, since (sometimes large) values that are harder to quantify, such as protecting public health, might be disregarded from assessments. This impression is supported by the less than 24% of green adaptation studies that consider health benefits in their assessments.

While not found to rank especially high, technological adaptations for water storage and management such as rainwater harvesting and wastewater reuse and recycling are on the whole considered to be economically efficient solutions. These results tend to be based on short-time frames, but higher BCRs could be expected with longer time considerations. Certainly, water storage and management will become increasingly important with rising temperatures. An estimated 2°C rise in global temperature could result in water shortages affecting between 1 billion and 4 billion people, predominantly in parts of Africa, the Middle East, Southern Europe and South and Central America. At the same time, higher levels of rainfall and flooding, especially in parts of South and East Asia, could affect between 1 billion and 5 billion people (Warren et al., 2006). Improvements in design, materials and construction techniques can improve the resilience of water infrastructures and lead to more efficient water management and storage technologies (at lower-cost) in the future. Scientific and technological progress can also be expected to improve climate pre- dictions and weather forecasts, enabling the design of more effective adaptation responses in the coming years (Stern, 2007).

Ineffective measures

Resettlement options for flood-prone communities are ranked among the least at- tractive solutions for dealing with climate change impacts. Governments that pursue this solution might offer incentives for relocation or aim to establish mandatory re- settlement programmes for vulnerable groups. For countries most at-risk from the impacts of climate change, i.e., islands in the Pacific, resettlement programmes are already being pursued as a matter of national policy. But this type of adaptation is often justified as a last resort solution. Not only do these measures involve considerable direct implementation costs, but they also come at potentially high social, economic and environmental cost. Displaced communities might suffer from loss of livelihood, debt and disintegration as a direct result of relocation. But mass migrations caused by climate change could also lead to spill over effects in neighbouring regions — political instability, economic and social pressures, and environmental degradation are among the potential adverse effects of such policies. Policy frameworks at various local, regional and international levels of governance should explore existing capacity and latent outcomes if they are to avoid the worse effects of climate-induced migration. For host nations, this might require thinking about infrastructure capacities, impacts on labour demand and supply, and how to best integrate migrant communities into society. International bodies should also strive for a global re-think of existing and prospective channels of voluntary migration, funding mechanisms, the need for humanitarian assistance, how to best deal with conflict resolution and emergency preparedness, and innovative mechanisms for linking migration to labour, sectoral or demographic deficits in countries.

A note on the ranking of options

Differences in discounting practices, economic and climate change scenarios, un- certainty treatments, non-market considerations, temporal and spatial scales, and equity, can raise uncertainty when deciding between options and subsequently weaken the case for action. This leads us to question whether, as it stands, CBA is an appropriate and justifiable means for prioritizing options. CBA undoubtedly has its limitations, but in most cases it is the most comprehensive and consistent available information for supporting decision-making. Findings also show that many adaptation actions have huge benefits compared to costs in spite of the limited basis on which they are calculated. Future assessments should strive to limit uncertainties and strengthen CBA outcomes by complementing analyses with other types of information - cost-effectiveness, multi-criteria, real-options and robust decision- making approaches will help to provide more complete evaluations in this regard. Users of CBA itself can also aim for more holistic considerations with respect to externalities, distributional effects, and how to best integrate issues of intra- and inter-generational equity within their assessments. Indeed, some of these aspects are included at least qualitatively in many CBA studies. A more complete treatment of these factors, however, will be fundamental for assessing the true value of adaptation and in supporting decision-making. This is particularly important now, at a time where cities are already undertaking adaptation plans and making serious investment decisions[11] that will condition (positively or negatively) future resilience.

2.4. Conclusion

Cost-benefit analysis of adaptation measures in urban environments faces a number of challenges pertaining to timescales, discount rates, scenarios, uncertainties, and the valuation of non-market costs and benefits. As a result, a number of issues arise that highlight the inadequacies of CBA for dealing with aspects such as equity, environ- mental justice, extreme or irreversible climatic events, and the sustainability of options.

Even so, the widespread and consistent use of CBA makes it an important economic tool for climate change adaptation. Its main advantage lies in its common basis for comparison (money), which enables decision-makers to assess the feasibility of a proposed policy or program. CBA also acts as a screening device against inefficient proposals (where the costs far outweigh the benefits), which is particularly

[11] A great deal of infrastructure investment will be decided in the following 20 years, accounting for up to US$90 trillion (New Climate Economy, 2016)

useful in public sectors for preventing inefficient public spending. Indeed, some have argued that current regulatory costs remain widely variable and unacceptably high (Tengs et al., 1995; Tengs and Graham, 1996) and better allocation of resources could be achieved with properly implemented CBA. CBA also supposedly increases transparency and accountability in decision-making by offering a common and simplistic language for users and stakeholders to understand. This also limits politically contentious decisions by requiring that all assumptions and uncertainties underlying analyses be revealed.

While there are numerous advantages to cost-benefit analysis, its application to environmental matters remains widely debated. As highlighted in this study, a major limitation of CBA relates to the numerous discrepancies between authors on how to handle aspects such as inter- and intra-generational equity, low-probability high-impact risks, distributional effects, and the integration of important non-market factors related to aspects such as human health, well-being, and the environment. More often than not, these aspects are disregarded within CBA due to quantification issues, which for many options may skew decision-making against protection and may adversely affect already marginalized groups. At present few studies apply extensions of CBA, such as multi- criteria analysis, adaptive pathways and real options analysis, which can help address some of these challenges. However, this is changing and more studies using these tools can be expected in the future.

It is important to note that these conclusions are based on a relatively small sample of the literature on adaptation. Furthermore, it is difficult to compare CBA across such diverse adaptation measures and contexts. Greater research into these distinct adaptations will no doubt provide more detailed and meaningful results. In addition, more work ought to be done on how to address the challenges of economic assessments of adaptation in developing regions, which as it stands, are underrepresented by the literature. Innovative financing for adaptation that shifts the burden of costs from victims to polluters, for example, will help developing cities utilize restricted resources and push beyond planning through to implementation. Future scholarship also needs to explore the potential magnitude of non-market costs and benefits of adaptation. Striving for more integrated valuation within assessments can help in this respect. Finally, gaining a more holistic perspective on the distributional effects of non-market impacts will help limit the likelihood of maladaptation and encourage measures that balance adaptation alongside other policy goals such as mitigation, economic development, health and wellbeing.

Chapter 3: Determining discount rates for the evaluation of land-use planning – An application of the Equivalency Principle

3.1. Introduction

Decisions with consequences that occur over the long-term are widely known in economics as inter-temporal choices. Indeed, inter-temporal decision-making has been studied during the last 80 years through the Discounted Utility (DU) model, formulated by Paul Samuelson (1937). The DU model assumes that society prefers to receive benefits in the short-term while delaying costs to the future, by "exponentially discounting the value of outcomes" as they occur further in time, thus placing decreasing weight on the value of future welfare. However, if lower discount rates give higher value to future generations more likely to suffer from environmental impacts, but come at a cost of greater economic sacrifices to the current generation, then what is the most appropriate discount rate to use?

The classical framework for representing inter-temporal choices has been widely disputed over the years for the use of market rates. Bromley (1998) says that traditional sustainability approaches based on commoditising natural assets, and making judgements of welfare and utility across generations (and across infinitely many time periods) cannot stand because the desires, valuations and preferences of future generations are totally unknown and unknowable to us. Based on this, Bromley asserts that we should follow rights-based approaches to sustainability wherein those living now agree to preserve 'settings and circumstances' for the future. Gowdy (2004) on the other hand, argues that based on the considerable evidence showing that people value the medium and distant futures the same (hyperbolic discounting), straight-line discounting (whereby the future is discounted at the same rate during all future time periods) may seriously underestimate the benefits of long-term environmental policies. After a comprehensive discussion on environmental discounting in his book Greenhouse Economics: Value and Ethics, Spash (2002) boils the debate down to one between ethics and economics. While acknowledging this, he ascertains that: 'The contradiction is that economics takes a very specific philosophical and ethical position and then tries to deny the relevance of ethics in economics. The conflict of values remains despite the attempts to remove their explicit discussion from the economic debate" (Spash, 2002, p. 188). A significant milestone came in 2007 with the Stern Review on the economics of climate change, which advocated for the use of near-zero discount rates for representing intergenerational preferences on climate change (Stern, 2007). Its publication received mixed reviews. Several leading economists, such as Dasgupta (2007) and Weitzman (2009), agree wholly with the use of low discount rates given the inadequacy of traditional neoclassical frameworks for addressing environmental issues characterised by irreversibility, uncertainty and long-term horizons. Others, while agreeing on the need for action on climate change, considered the Review incomplete and its conclusions ambiguous from an economic perspective (Tol, 2006; Tol and Yohe, 2006). Indeed, in his appraisal, Nordhaus (2007) argues that the Review confuses two fundamental concepts of discounting. The first, defined as the "real interest rate", relates to the annual percentage increase in the purchasing power of a financial asset, measured by the nominal or market interest rate on that asset minus the inflation rate (Frank et al., 2007). The second, called the "pure rate of social time preference", is concerned with the economic welfare of households or generations over time. It describes the rate at which society is willing to postpone a unit of current consumption or expenditure in exchange for future consumption. The pure rate of social time preference has been proposed as a social discount rate for public projects in general, given the consideration of intergenerational equity for long-term projects (Scarborough, 2011). Therefore, unlike the real interest rate, which deals with future goods or investments, the pure rate of social time preference involves the discounting of future welfare. In this case, a discount rate of zero would ensure that present and future generations are treated equally, whilst a positive rate would imply a reduction in the value placed on the welfare of future generations compared to the present generation.

When discussing the use of near-zero rates proposed by Stern, or Nordhaus's support of real (market) interest rates close to 6% per year, Beckerman and Hepburn (2007) assert that the choice of either alternative is not trivial, and may have a decisive influence when assessing the economics of climate policy. Instead, they propose an intermediate approach based on the use of stated preference surveys, behavioural experiments and methods for determining discount rates reflective of social preferences. Conversely, Philibert (2006) proposes to assign a growing value over time to environmental assets that are not substitutable and not reproducible, or alternatively, he suggests the use of declining discount rates to account for the uncertainty of future economic growth. Others, such as Cropper and Laibson (1998), Gollier (2008) and Groom (2014) agree with Philibert's assertion of declining rates. Chichilnisky (1996) argues that no generation should prevail over the other, and similarly proposes the use of a conventional, market-based, discounting approach in the near-future and a rate of zero after an inflexion point. Certainly arguments for the use of declining discount rates are often justified on the basis of: uncertainties related to market-based rates or behavioural changes in the long-term, or due to the aggregation of heterogeneous pure rates of social time preference. It seems that during the last decade a non-official consensus has been reached in favour of social discount rates that decrease in the long-term (Groom, 2014).

Since the early 2000's the notion of dual-discounting has been emerging as a way to value environmental goods and services separately and differently from other costs and benefits (Tol, 2003; Yang, 2003). For example, Gollier (2010) argues in favour of an ecological discount rate smaller than the economic discount rate, where he estimates that changes in biodiversity be discounted at a rate of 1.5%, while changes in consumption be discounted at a higher rate of 3.2%. By separating the environment from other market goods and services, the approach ensures that future environmental assets are not undervalued or that the [economic] discount rate applied to them is not too large (Gollier, 2010). Indeed, as Weikard and Zhu (2005) argue dual rate discounting can be justified in cases where future prices for environmental goods are unavailable, or when market goods and environmental goods are not substitutable. This seems reasonable given that many environmental restoration or enhancement projects carried out by governments would be otherwise unable to meet decision-making criteria based on conventional CBA and discounting practices (Almansa and Martínez-Paz, 2011). But Green and Richards (2018) argue that the way that humans value monetary goods should not be confounded with the way they value environmental goods. Indeed, in their paper based on experimental evidence, the authors find that individual discounting behaviour, while varying widely across environmental goods, generally tends to be exponential, such that individuals discount environmental goods at lower rates compared to monetary goods. The evidence-base suggests that humans share a complex relationship with the environment unlikely captured by traditional economic valuation methods. Supporting this point, Adger et al. (2011) observe that climate change policy tends to disregard the relationship between aggregate measures of human welfare and the environment, that is, the "emotional, symbolic, spiritual, and widely perceived intrinsic values of the environment."

The main focus of this paper explores the complex relationship between people and the environment. In particular, it seeks to address the various trade-offs between conservation and development, and the common undervaluation of natural resources within conventional decision-making frameworks. Building on the literature on dual-discounting, this study suggests an approach for determining the discount rate for environmental assets in the case of land-use planning – the so-called Equivalency Principle (EP). This is based on the normative proposal explained in Chiabai et al. (2013), which argue that when one of two identical pieces of natural land located in the same administrative unit has been granted permission for development, market distortions stemming from regulations and externalities arise that will cause these two lands to be valued differently. This situation generates an anomaly that potentially may have deep ethical and environmental implications, as it may generate incentives to urbanise natural land rather than to use or restore existing urban land. The authors propose that both pieces of land should be valued equally, as the present value of both is at least equivalent, and subsequently, future generations are likely to give them equal utility and economic value. An important benefit of this approach is that it avoids making assumptions about the expected welfare or growth rate of consumption of future generations, and the magnitude of projected uncertain impacts for example due to climate change, which might materialise differently in the future.

Based on the EP, this paper estimates discount rates for several types of natural assets across Europe, based on the hypothesis that rates are likely to differ geographically, reflecting the preferences of the society where the land or natural resource is located. The objective of this study is thus to develop the EP as a practical rule of thumb that could guide investment decisions in the context of environmental and resource economics, and help to justify the use of lower-than-market discount rates for valuing environmental assets and ensuring sustainable land-use planning on both ethical and economic grounds.

The rest of the paper is organised as follows: Section 3.2 first discusses the theoretical basis of the EP including its economic rationale and caveats, followed by an explanation of the methodological approach applied in this study Section 3.3 presents the results for over 300 sites across Europe. Section 3.4 discusses some of the main findings and section 3.5 is devoted to conclusions.

3.2. Method

3.2.1. Foundations of the EP

As discussed previously, dual discounting can be used by Governments and donor agencies (e.g. financial institutions) as an additional policy instrument for environmental protection. In an ideal scenario, this would imply using market rates for projects that do not affect the environment but lower rates, such as those derived from the EP, for projects that do. This is justified on the basis that it is reasonable to expect a higher level of scarcity of natural resources in the future and investments to preserve such assets today need to take account of this. Of course, threats to the environment, i.e. encroaching development in natural areas to sustain economic growth and potentially catastrophic impacts due to future climate change, may deplete environmental resources to such an extent that damages become irreversible. Moreover, while the exact relationship between the discount rate and the exploitation of natural resources is unknown, the general consensus is that the higher the discount rate, "the faster the depletion of exhaustible resources and the more intense the harvesting of renewable resources in the future" (Markandya and Pearce, 1991, p. 148). The EP offers one way of addressing this by estimating a range of discount rates that can be used in cost-benefit analysis carried out for investment projects affecting natural land.

Let us now, for illustrative purposes, imagine two plots of natural land located in the same area, N1 and N2, which have identical environmental and geographical characteristics (slope, ecosystem, proximity to infrastructures, etc.). Having both the exact same characteristics today, the current value of both plots of land would be the same. If their characteristics do not change and both plots remain in a natural state in the long-term, then their utility is expected to be the same. However, if one of the plots is granted permission for development today then we can expect a significant increase in its market price, while the value of the natural land stays unchanged. Here, the administrative act of 'granting development' causes one of the lands to be valued higher, despite the inherent characteristics of both plots of land remaining the same. While some may argue that the added value reflects the expected stream of private benefits stemming from future development, the argument neglects the almost certain (and irreversible) loss of environmental externalities caused by such (or any type of) development. Moreover, the shift in land values increases the attractiveness of developing on the land valued lower, which means policy-makers are economically incentivised to urbanise natural land rather than to use or restore existing brownfields for development projects. As Loures and Vas (2018) postulate the process is further complicated by the numerous typologies and characteristics attributed to brownfields, which encompasses land types such as abandoned land, contaminated land, derelict land, underutilised land and vacant land. Without clear definition, different land types can likely be regarded as substitutable, without recognising the relative difference in intrinsic environmental benefits associated with each.

McCarthy (2002) asserts, brownfield reuse is fundamental for wider community goals aimed at achieving environmental protection, revitalising cities, and reducing suburban sprawl. Such distortions in the market must be addressed if we are to ensure the sustainable protection of vital environmental assets and services, particularly given the already impending challenges of climate change for future generations. The solution offered by Chiabai et al. (2013) suggests that discounting may be used to regain the equivalency in the present value of both plots of land. This is done by equating the discounted sum of the flow of benefits of the natural land with the current market price of the development land, regardless of whether it has been designated for natural, residential or industrial purposes. The objective of this approach is not to derive relative values for the purpose of valuing natural land, but rather it specifically chooses to focus on the discount rate as a practical tool for informing land-use decision-making in cases involving the environment. In fact, the main strength of the approach stems from the idea that policy-makers can easily integrate its concept into cost-benefit appraisals for investment projects irrespective of time, scale or contextual setting. In fact, policy makers often have serious difficulties to choose the discount factor or this is given by financial authorities with no environmental or ethical consideration involved.

In practical terms, if plot N_1 is zoned as urban (U), either for residential or industrial use, then $N_1 = U$; while N_2 remains in its original state (N) (Figure 6). Here, the market price of the development land becomes greater than that of the natural plot of land ($P_{N1} = P_U > P_{N2}$). The value of N_2, usually estimated as the present value per hectare (PV_N), is often determined by non-market valuation methods, and should represent the Total Economic Value (TEV) of the natural land, comprising both use and non-use values. Using the conventional equation for the present value, the EP can be expressed as follows:

$$PV_N = \sum_{t=1}^{T} \frac{{V_N}^t}{(1+d)^t} = P_U \quad (1)$$

Where PV_N is the TEV of the natural land; V_N is the flow of benefits of the natural land in time t; d is the discount rate; and P_U is the price per hectare of the development land. When time extends to perpetuity the formula can be simplified to the following expression (Mills and Hamilton, 1994):

$$PV_N = \frac{V_N}{d} = P_U \quad (2)$$

Figure 6. Two pieces of natural land (N1, N2) of equal properties selected to illustrate the application of the EP

We can justify extending time to infinity on the basis that human welfare depends on the quality of ecosystem services and, because of this, their total value for the economy and for human society may be infinite (Costanza et al., 1997). While the above formula assumes that the benefits are constant over time, flows can be expected to increase over time in real terms as a result of growing real incomes and increasing scarcity of services from natural capital (Krutilla, 1967). In this case the value of N for a finite timescale would be:

$$PV_N = \sum_{t=1}^{T} \frac{V_N(1+g)^t}{(1+d)^t} \quad (1')$$

Where g stands for the growth rate or appreciation of benefits of natural land over time. This can also be expressed as:

$$PV_N = \sum_{t=1}^{T} \frac{V_N(1+g)^t}{(1+d)^t} \approx \sum_{t=1}^{T} \frac{V_N}{(1+d-g)^t} \qquad (1'')$$

When time extends to infinity the formula can be simplified to the following expression:

$$PV_N = \frac{V_N}{(d-g)} = P_U \qquad (2')$$

Solving for Equation 2' we can obtain the discount rate that equalises the values of both lands:

$$d = \frac{V_N}{P_U} + g \qquad (3)$$

Equation 3 is based on the consideration of increasing flows of benefits over time. If growth is not taken into account, g would equate to zero.

Alternative policy instruments for achieving environmental protection can often be classified into two main approaches: "command and control" and "market-based" methods. While the first approach, command and control, relies on various (ambient, emission and technology) standards to promote socially desirable behaviour (Field and Field, 1997), market-based approaches instead aim to incentivize firms (e.g. through taxes and pollution rights) to make more sustainable choices. Both policy instruments face a number of political economy issues however. For example: conventional command and control approaches have often been criticized for not meeting environmental objectives at least-cost, while various political and technological constraints make market-based approaches ill-suited for dealing with certain environmental problems (Berck, 2018). In cases where traditional policy instruments are unable to effectively meet environmental objectives, such as the land planning example described before, the EP offers an alternative approach for enhancing environmental protection. Contrary to implementing a new environmental tax or passing additional legislation, which are highly political processes that may take years to carry out, one of the main advantages of the EP is that policy makers can use it as a basis for determining environmental discount rates immediately and its application is theoretically valid under only two assumptions:

1. Past decision making by the administrative unit[12] of reference on development versus protection of natural assets has been close to socially optimal[13], so that the marginal present value of the natural land is equal to the marginal present value of the adjacent development land (Chiabai et al., 2013), and;

2. Future generations may be affected in the long run by decisions made over the land under consideration

However, while optimal decision-making would imply policy-makers are making perfect marginal trade-offs between preservation and development, the assumption here is that (while all else is optimal) land-use decisions have not been able to properly account for the myriad of environmental externalities associated with natural lands. This can be the case very often in decisions related to land use planning. Indeed, as Chee (2004, p. 549) posits: 'decisions concerning ecosystem management are often complex, socially contentious and fraught with uncertainty.' This relates, for example, to difficulties in realizing the full range of implicit regulating, provisioning, cultural and supporting ecosystem services of the environment; in capturing the true 'market' value of complex environmental functions (e.g. aesthetic and cultural worth) where no market exists, and; in appropriately determining the welfare that environmental preservation would bring to future generations greater affected by climate change. Failure to internalize environmental externalities within land-use decision-making has meant local governments have fewer policy levers to disincentivise development through mandatory or voluntary regulations, with zoning remaining the most widely accepted control tool for land-use planning (Geoghegan, 2002).

Figure 7 illustrates the concept of near-optimal decision-making using a stylized production possibility frontier (PPF). The figure is divided into three areas (A, B and C):

- Area A – represents a situation where decision-making has been close to optimal. Therefore, the marginal benefit of developing an additional unit of nature is approximately the same as the cost. This is the only area where the EP explicitly applies.

- Area B - when an area has been over-developed the EP should not be used as protecting the remaining natural land will far outweigh the benefits of further development. This can be seen when moving from point B1 to B2, where a small gain in development causes a great loss in environmental benefits.

[12] Chiabai et al. (2013, p.540) define administrative unit as "the public administration having the responsibility for land use planning and for granting building permits in a specified area."

[13] i.e. in terms of legality, cost-efficiency, feasibility etc.

- Area C – the reverse scenario is also possible. In regions that are severely under-developed, the cost to society from the loss of some environmental services will be far outweighed by the benefits that development will bring. This is illustrated by a shift from point C1 to C2.

The second assumption required to justify the use of the EP is that future generations are affected in the long run by decisions taken on the land. This assumption is easy to meet as natural land that has been degraded or converted can rarely be restored to its original state (Moreno-Mateos et al., 2017, 2015). This irreversibility highlights the importance of using the EP in decision-making in order to preserve the remaining natural land for future generations by incentivizing the use of brownfields for new construction instead of developing on natural parcels of land.

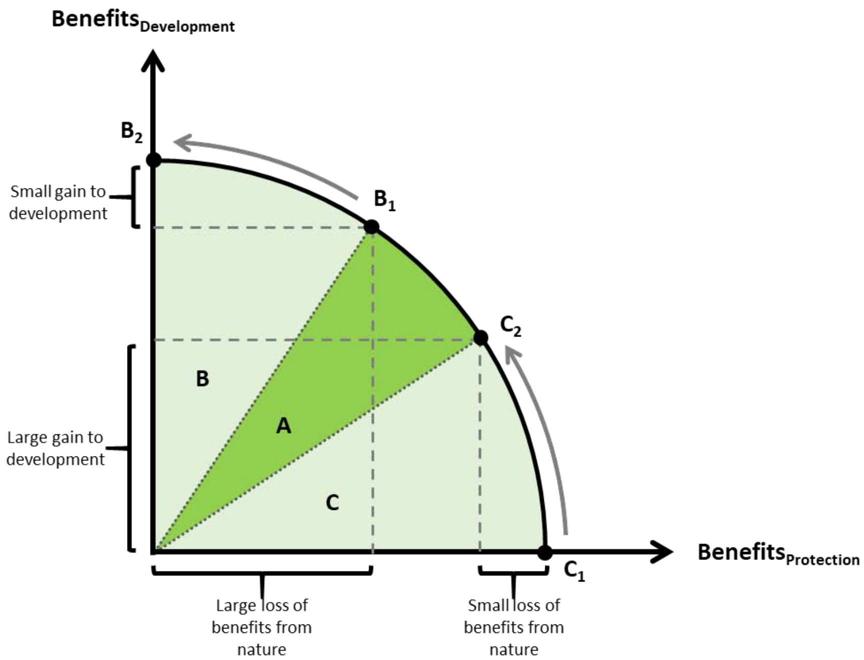


Figure 7. Conditions of socially optimal decision-making on land-use allocation

3.2.2. Data Collection

In order to satisfy the pre-conditions of the EP, two types of data were collected; the first representing the non-market values of natural land, and the second representing the prices of neighbouring lands with similar environmental characteristics designated for a certain type of development (i.e. commercial, industrial, residential) within the same administrative unit. Data was collected from sites across Europe[14] in order to assess how the application of the EP would change according to different contextual settings and a sensitivity analysis was conducted to better understand the ranges of discount

[14] All observations come from Europe except one from Turkey, but for simplicity we will refer to all countries as European

rates observed. For the purposes of presenting an illustrative example of how the EP might apply, and to better understand the drivers of differences in values, a simplified approach was adopted that does not consider the impact of various economic growth rates in the future. This was intended to eliminate the inherent uncertainty in such values.

The first stage of the methodology involved collecting data on the values of natural land. This involved conducting an extensive literature review of both the scientific and grey literature, using widely recognised search engines such as Google Scholar and Web of Science. A keyword search was performed to detect primary valuation studies that measured the TEV of natural land. The TEV is defined as "the sum of the values of all service flows that natural capital generates both now and in the future – appropriately discounted" (Kumar, 2012, p. 188) and encompasses: direct and indirect use values, option values, existence values and bequest values. Because of difficulties in capturing and accounting for all components of TEV (Anderson et al., 2016), as well as the conceptual and empirical difficulties involved in adding up various component values of TEV (Randall, 1987), studies that included at least one component of TEV were included. Both direct (stated-preference) and indirect (revealed preference) approaches were included to limit the potential bias associated with considering one approach, as well as to demonstrate the flexibility of the EP. Due to the large volume of research conducted in earlier years, a time-range between 1990 and 2015 was chosen. All values were converted to EUR 2016 prices using the Purchasing Power Parity (PPP) and Consumer Price Index (CPI) conversion factors provided by the Organisation for Economic Co-operation and Development (OECD)[15].

After the initial stage was complete, the next stage involved collecting data on neighbouring lands designated for development purposes. At the aggregate level, Eurostat is currently the only public database available that provides land prices at the EU and national level. These values focus predominantly however, on agricultural land types, and lack the geographical detail for analysis at the district or provincial scale. Other sources, including national government agencies and national statistical offices were searched, some of which focused exclusively on agricultural land types and lacked data on prices for alternative land uses. Most official sources however, such as the Valuation Office Agency (VOA) in the UK, the Federal Statistical Office in Germany, the Spanish Ministry of Public Works and Transport in Spain, the Belgian Statistical Office in Belgium, the Central Statistical Office of Poland and the National Land Survey of Finland, provided relevant data on land markets, including data on prices for building land, such as residential and commercial land. For the remaining countries, publicly available regional real-estate market reports were used to gather data on prices of land designated for particular development purposes.

[15] Database of OECD PPP and CPI factors can be found at: http://stats.oecd.org.

The literature on natural land values and the data on prices of adjacent development lands were sorted and categorised within a database. Studies with missing information or that were located in regions with no data on land prices were excluded from the database. The final database consisted of 47 studies and 308 site values, across 11 European countries. A summary of the literature on the values of natural land can be seen in Table 6, and relative data on market prices of development land can be found in Appendix V.

Table 6. Description of natural land studies observed in the literature

Country	Habitat(s)	Land Area (ha)	Value ha/yr (EUR, 2016)	Source(s)
Belgium	Fresh & saltwater coastal areas; forest	540 - 2,500	1,505 – 6,779	(Desmyttere and Dries, 2002; Moons, 2002; ten Brink et al., 2011)
Finland	Forest	20,000	426 - 495	(Kniivilä et al., 2002; ten Brink et al., 2011)
Germany	Wetlands	15,000	12,048 – 20,712	(Meyerhoff & Dehnhardt, 2007)
Greece	Wetlands, water body, forests, grassland, coastal	11,400 – 146,680	9 – 36,514	(Birol et al., 2006; Ghermandi et al., 2010; Pavlikakis and Tsihrintzis, 2006)
Italy	Grassland, coastal, forest	3,000 - 5,500	2 – 5,750	(Bellu and Cistulli, 1997; Marzetti et al., 2011; Zoppi, 2007)
Netherlands	Forest, grassland, water body	5,200 - 5,500	1,364 – 14,127	(Hein, 2011) }, (ten Brink, et al., 2011); (Kuik, et al., 2006); (Hein, et al., 2006)
Poland	Forest	32,764	23,290	(Povazan, et al., 2014)
Spain	Water body, grassland, coastal, forest, wetlands	117 - 5,550,000	6 – 258,527	(Ramajo-Hernandez & del Saz-Salazar, 2012) (del Saz-Salazar & Rausell-Köster, 2008) (Hoyos, et al., 2007) (ten Brink, et al., 2011) (Mogas, et al., 2006) (Galarraga, et al., 2004)
Sweden	Forest	3,717,407	4 -20	(Bostedt & Mattsson, 2006)
Turkey	Wetlands	14,750	387	(Gürlük, 2010)
UK	Wetlands, grassland, water body, coastal, woodland, mountain, forest	67 -179,284	9 – 94,860	(Luisetti, et al., 2010) (Everard, 2009) (ten Brink, et al., 2011) (Turner, et al., 2004) (Bateman, et al., 2000) (Klein & Bateman, 1998) (Willis, 1996) (Cobbing & Slee, 1994) (Maxwell, 1994) (Hanley & Spash, 1993) (Willis & Garrod, 1993) (Bishop, 1992) (Willis, 1990)

3.2.3. Data description

Considering the availability of data on natural land values and market prices of development lands, the largest estimated range of discount rates was calculated for the United Kingdom with a total of 90 values, followed by the Netherlands and Greece, with 64 and 48 values, respectively (Fig. 8). Over 70% of entries employed the use of stated preference methods, such as the Contingent Valuation Method (CVM) to value natural site benefits. Although such methods have been subject to certain controversies and potential biases (Diamond and Hausman, 1994), the large share of studies adopting this approach is reflective of the fact that stated preference methods are often the only available tool to value certain sites or to elicit certain types of values. In addition, despite their limitations, such approaches for ecosystem service valuation can provide important insight for decision-making where no alternative exists. Indeed, as Bingham et al. (1995, p. 87) assert, while improving economic valuation of ecosystem services may lead to improved decision-making over environmental issues, it will not solve for the "collective political decisions about distribution issues, including rights to resource use to future generations or within the present generation."

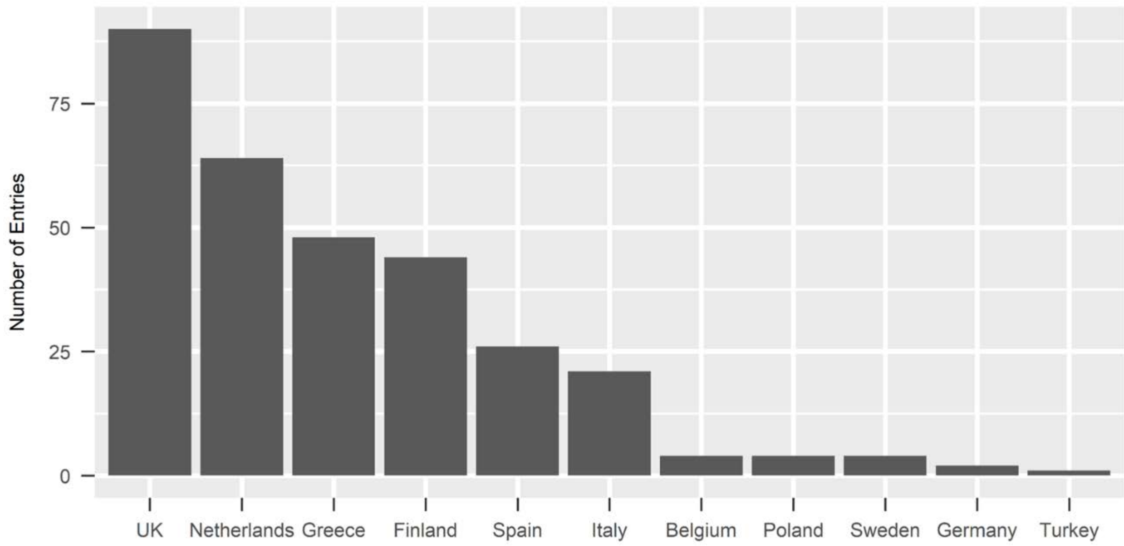


Figure 8. Number of discount rates estimated for each country

Studies included a range of provisioning, supporting, regulating and cultural ecosystem services (Table 7), which are defined as the benefits that humans obtain from ecosystems produced by interactions within the ecosystem (Assessment, 2005). Most common were provisioning services such as fresh water provision and the supply of raw materials, as well as cultural services such as tourism, or the recreational or aesthetic value of the land. Other services included flood and erosion control, and carbon sequestration (regulating services), as well as biodiversity and nature conservation (supporting services). Habitat types also varied across studies, with most values estimated for forests (137), followed by wetlands (129), coastal areas (41), grasslands (30) and water bodies (15) (Figure 9). Table

7 presents general descriptions of methods, habitats, land status, and types of ecosystem services observed in the literature.

Table 7. Description of habitats, ecosystem services, valuation methods and status of natural lands

	Typology	Description
Habitats	Forests	Boreal, coniferous, deciduous, forested swamps, woodland
	Wetlands	Floodplains, rivers, lakes, lagoons, marshes, mud flats, swamps
	Grassland	Farmland, meadows
	Coastal	Shoreline, coastline, dunes
	Mountain areas	Basins, cols, inland hills, valleys
	Green urban areas	Parks, green land, greenbelt
Ecosystem services	Provisioning	Freshwater provision, timber, wood fuel, agriculture, forestry, fisheries
	Regulating	Erosion and flood control, carbon sequestration, water purification and regulation, wind protection
	Cultural	Recreation, tourism, cultural and historical heritage, eco-tourism, education
	Supporting	Nutrient cycling, habitat and biodiversity creation and conservation
Valuation methods	Contingent valuation (CVM)	
	Choice experiment (CE)	
	Benefit/value transfer	
	Cost-based approaches	
	Travel cost method (TCM)	
	Hedonic pricing	
Status of land	Protected	National parks, nature reserves, sites of special scientific interest, sites of community importance, Ramsar and UNESCO sites, environmentally sensitive areas
	Unprotected	Urban parks, green land, agricultural land

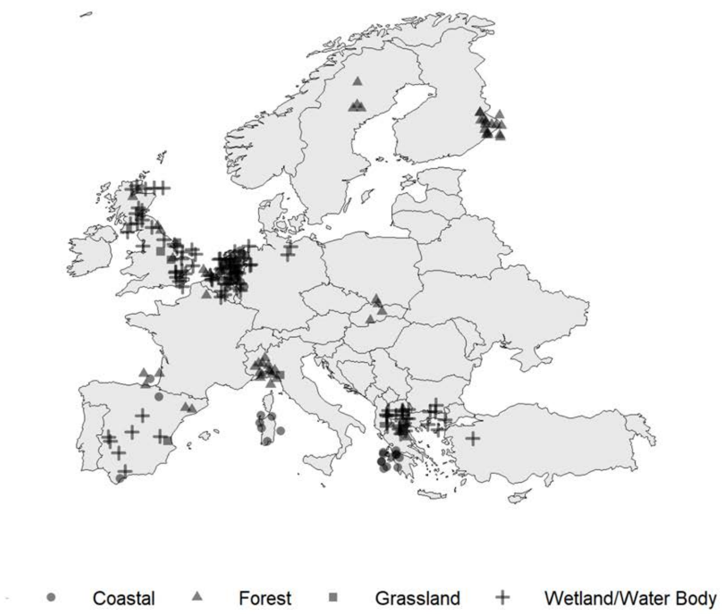


Figure 9. Distribution of habitat types by country

3.3. Results

3.3.1. General results

A box plot showing the distribution of discount rates by habitat type is shown in Figure 10, and the median, mean, maximum and minimum result ranges are presented in Table 8. Average discount rates ranging between 0.3% and 1.1% were estimated across habitat types. Coastal areas represented the highest discount rates on average (1.1%), followed by wetlands (0.6%), grasslands (0.3%), forests (0.3%) and water bodies (0.3%). As figure 10 shows, excluding outliers[16], the majority of discount rates across habitats fell below 1.2%, with median values ranging between 0% (in the case of water bodies) and 0.2% (in the case of wetlands). The higher discount rates for coastal areas is attributed to the generally higher social values placed on these habitats, with an average TEV of approximately €24,028 compared to €11,674, €6,603, €4,621 and €1,749 for wetlands, forests, grasslands, and water bodies, respectively. Certainly, these habitats tend to encompass a wide range of values, such as: biodiversity, nature conservation, aesthetic, recreation and tourism values.

[16] See Appendix VI for box plot of discount ranges by habitat type including outliers

Table 8. Estimated discount rates by habitat type (%)

	Coastal	Forest	Grassland	Water body	Wetland
Median	0.0	0.1	0.1	0.0	0.2
Mean	1.1	0.4	0.3	0.3	0.6
Max	10.9	6.8	1.8	1.4	11.0
Min	0.0	0.0	0.0	0.0	0.0
No. of entries	**41**	**137**	**30**	**15**	**129**

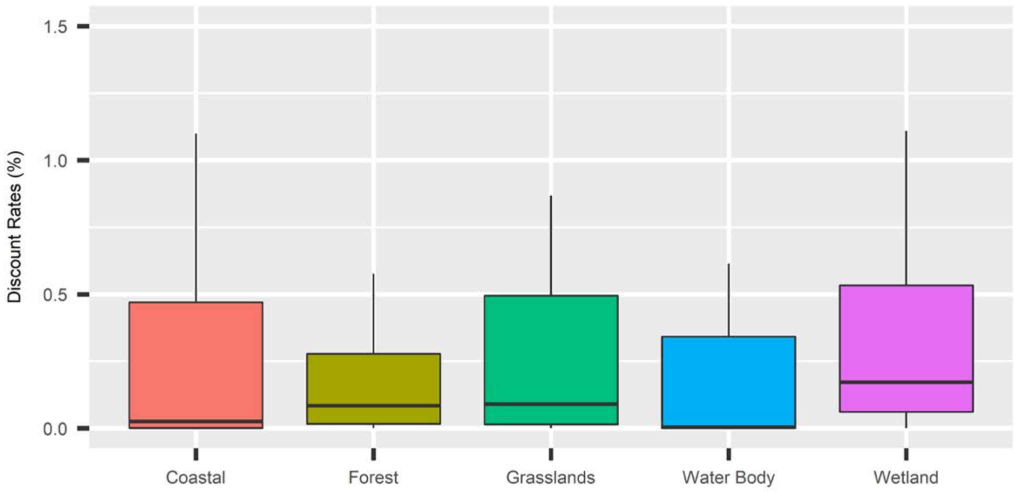


Figure 10. Box plot showing discount rates by habitat type

The discount rates observed by country are presented in Table 9. Average discount rates ranged between 0% and 3.8%, with an overall mean value of 0.6% across all countries. Overall, the majority of countries displayed average discount rates below 1%, with the exception of Germany, Poland and Spain, with rates of 1.4%, 3.8% and 1.7%, respectively. Maximum rates of 10.9% and 11% were found for sites in Spain and the UK, but with mean values of 0.7% and 1.7%, respectively, these were considered to be outliers. Indeed, the next highest discount rate was significantly lower, estimated at 6.8% in the case of Poland[17]. The high variation in development land prices for sites in Poland, ranging from €340,000 to €1,020,000 (Appendix V) can explain the difference of 4% found between the minimum and maximum discount rates for this country. Similarly, for the UK and Spain, the large variation in discount rates can be attributed to the large differences in natural land (Table 6) and development land values (Appendix V) for these countries. Across development sites, estimated discount rates ranged between

[17] As represented in Appendix VI, the value of 6.8% is also considered to be an outlier, and may be an overestimation of the maximum discount rate for this country.

0.4% and 1.2%, with general development representing the highest rates on average, followed by industrial (0.9%), office (0.5%), residential (0.4%) and commercial (0.4%) land uses (Table 10).

There has been much debate among economists as to whether the demand for environmental protection is disproportionately distributed across income groups. Indeed, conservation policies may be seen as regressive based on the notion that net benefits will be larger for individuals with high incomes than for those with lower incomes (Boardman et al., 2017). This is evidenced prominently in the case of contingent valuation studies, where a strong correlation is found between income and environmental protection. In such cases, individuals are often asked to value environmental resources based on conditions such as the welfare they derive from and their willingness-to-pay (WTP) for conservation programs.

Table 9. Estimated discount rates by country (%)

Country	No. of entries	Median	Mean	Max	Min
Belgium	4	0.2	0.2	0.3	0.1
Finland	44	0.5	0.9	4.5	0.0
Germany	2	1.4	1.4	1.8	1.1
Greece	48	0.1	0.4	3.1	0.0
Italy	21	0.0	0.0	0.3	0.0
Netherlands	64	0.1	0.2	1.3	0.0
Poland	4	3.0	3.8	6.8	2.3
Spain	26	0.1	1.7	10.9 (8.5)[a]	0.0
Sweden	4	0.0	0.0	0.0	0.0
Turkey	1	0.0	0.0	0.0	0.0
UK	90	0.3	0.7	11.0 (3.7)[a]	0.0
Total	352	0.2[b]	0.6[b]	11.0[b]	0.0[b]

[a] () values in parenthesis indicate next highest value

[b] Represents the average value across all cases

Consequently, a valid assumption would be that individual responses would depend largely on personal factors, such as the amount of disposable income available to them, and the proportion of which they are willing to allocate to environmental causes, as well as how much they value the environment relative to other non-environmental goods and services. For dealing with distributional issues across socio-economic groups, Pearce (2003) argues that both the income elasticity of demand and the income elasticity of WTP are useful measures for measuring the effect of income on levels of environmental protection and in classifying environmental goods. Where the former refers to the change in the quantity demanded of some environmental asset in response to a small change in income, the latter deals with the change in WTP for some environmental asset with changes in income. However, since the focus of most environmental policy is on public goods that have some quantity constraint, Pearce argues that the income elasticity of WTP is the more relevant measure of the relationship between income and the environment (Flores and Carson, 1997).

Table 10. Estimated discount rates by development type (%)

	General development	Commercial	Industrial	Office	Residential
Median	0.1	0.1	0.3	0.2	0.1
Mean	1.2	0.4	0.9	0.5	0.4
Max	10.9	2.9	11.0	4.1	4.5
Min	0.0	0.0	0.0	0.0	0.0
No. of entries	42	47	88	27	104

Since a large extent of the studies evaluated employed CVM studies to measure the value of natural land, and given the strong empirical relationship between income and environmental quality within CVM, a sensitivity analysis was conducted to test the relationship between various elasticities and the impact they might have on the EP and subsequent discount rates (see Appendix VIII).

3.3.2. Hypothetical illustration of the EP in Spain

To show how the EP would work in practice, we present an illustrative case study where we imagine a development project is undergoing an investment appraisal. Using the data derived for Spain as an example, let us assume that a residential development project has been proposed for a natural site that has been estimated to generate annual environmental benefits (or a TEV) of €22,309 per hectare. Given that the development will likely eradicate most (if not all) of the natural benefits of the land, we can use this figure as a proxy for the environmental (social) cost of development. Now let us imagine that for the same plot of land the developers foresee a positive net economic impact of €40,000 annually. The local authorities must now make a decision over whether the development goes ahead or not. In order to make their decision, they wish to consider the net impacts of the project over the next 40 years. This requires comparing the social cost of building on the land with the expected stream of economic benefits generated by the project. By simply comparing the project's costs and benefits, we can examine the impact that different discount rates would have on the final outcome of the decision. While the economic benefits are discounted using a market-based rate of 6%[18], we consider three scenarios for discounting the social cost of the project: the first uses the same market-based rate of 6%, the second applies a rate

[18] This estimate is in line with the ADB, which reports a social discount range of 4-6% for various sectors in Spain (Zhuang et al. 2007)

of 4% as suggested by Gollier (2008), and the last uses the discount rate determined by the EP[19] (Table 6).

Table 11. Cost-benefit analysis example of a hypothetical investment project in Spain using a time horizon of 40 years. All estimates are in EUR (2016).

A. Benefits of the project		B. Environmental costs		Net Present Value (A-B)
Discount rate applied to project benefits (%)	Present value of project benefits	Discount rate applied to environmental costs (%)	Present value of environmental costs	
6%	641,851.87	6%	357,971.54	283,880.33
		4%	463,859.13	177,992.74
		1.39%	703,318.67	-61,466.80

The results of the hypothetical cost-benefit analysis presented in Table 11 show us that the investment project would generate a positive net impact over 40 years of €177,993 and €283,880 when applying discount rates of 4% and 6%, respectively. However, when using the 1.39% discount rate derived from the EP, the project is shown to result in a negative net-present value of -€61,467. Thus, the project would only be justified under the first two scenarios. This demonstrates how the discount rates applied in traditional cost-benefit analyses can be largely biased (Chiabai et al., 2013), while a more sustainable approach would be to use site-specific discount rates (such as those from the EP) to ensure that affected environmental assets are being properly accounted for. The reason being that, ceteris paribus, in countries where the environment is highly valued rates could be higher than in those where the environment is valued less, and in countries where market prices of development land are high, we can expect to find lower discount rates than in countries where the market price for development land is low.

3.4. Discussion

The application of the EP could represent an interesting instrument to re-establish the equivalency between the economic importance of two types of land (natural land and natural land designated for development) accounting for all attributes. In practical terms, this means that the discount rate derived from the EP can favour the protection of natural land in investment projects concerning development choices over the territory. This is because current assessment methods are unable to properly account

[19] This is estimated using the conventional formula for the EP, calculated based on a natural land value of €22,309.67 and a development land price of €1,605,229 situated in Valencia, Spain

for the total value of natural assets and environmental resources, particularly those that have no close monetary substitutes (Dietz et al., 2016b). As a result, management regimes rarely consider the aggregate measures of human welfare, such as cultural or psychological values and the irreversible loss of nature, which are of at least equal, if not growing importance (Adger et al., 2011). The EP therefore reinforces the idea that discount rates should differ geographically on the basis of local specificities, including the preferences of society on development, environmental policies and environmental resources. That is, in countries where great value is already given to natural land or environmental resources there is less of a need to adjust discount rates to guarantee their protection. In contrast, in areas where little value is given to natural resources, the EP can be used as an additional policy instrument to ensure protection by using lower discount rates during project appraisal.

Our results show that factors such as the type of habitat, geographical location and the type of land-use development can play a role in shaping discount rates derived by the EP. In the case of the latter, for example, discount rates were estimated to be lower for residential land use (0%) when compared to industrial land use (1%) across study sites (Table 10). This shows that the magnitude of the discount rate depends on both the TEV and the market price for development land. As mentioned previously, this implies that the higher the price of development land, the greater the need to use discounting to generate the right incentives to protect natural land. And equivalently, the lower the value attached to the natural environment, the greater the need to ensure its protection through appropriate discount rates. Certainly, with average discount rates below 1% for most countries (Table 9), the main findings indicate a support for policy decision-making that sustains the protection of natural lands and ecosystems. By essentially equating the long-term value of protection and the cost of development on natural lands through locally specific discount rates, the EP provides an alternative means of assessing the financial viability of projects and programmes that could detrimentally impact conservation efforts and sustainable landuse practices.

Taking the case of climate adaptation for example, the EP can be an important determinant for deciding between adaptation options that may have fundamentally different impacts on the use of natural resources. This is an important consideration since decisions taken on adaptation today may have negative environmental and social implications for future generations, and since the value of future generations is often only considered in todays decisions through formal discounting methods in economics (Adger et al., 2009). This raises concerns as to how we can reconcile the non-market and non-instrumental aspects of the environment with the economic metrics employed in climate change decision-making, as well as how to deal with the risk of irreversible loss. Indeed, while economic losses are easily accounted for in conventional decision-making frameworks on climate change, ecological, cultural and psychological losses are often, if not always, underemphasized (Adger et al., 2011). This is demonstrated within this analysis by the high frequency of discount rates estimated to range between 0% and 1%, suggesting that natural sites are commonly being undervalued (Appendix VII). Policy development must therefore recognise that successful adaptation is not limited to the efficiency of economics or engineering, but depends equally, if not more, on the wider societal and environmental benefits of measures. Subsequently, as Adger et al. (2011, p. 20) note: “there is a need for more geographically and culturally nuanced risk appraisals that allow policy-makers to recognise the diverse array of climate risks to places and cultures as well as to countries and economies.”

Certainly, application of the EP and the analysis presented here maintains both benefits and limitations. Of noteworthy, one important ancillary benefit of applying the EP relates to the uncertainty of expressing TEV as a unit per hectare. While the use of common units of measurment is crucial in economic valuation for comparative purposes, uncertainty lies in calculating a flow value by simply dividing the total value of an entire site by its area. Indeed, much of this is related to identified cognitive biases such as scope insensitivity in CVM (Kahneman, 2000). As a result, values per hectare may be lower for larger sites, and higher for smaller sites, while the total TEV may be similar in magnitude. In some cases this may lead to unrealistic values of natural land, as the true value per hectare may not be appropriately reflected. This phenomenon has been widely recognised in welfare economics, where the overall size of a natural site may affect is value per unit area, in accordance with the concept of decreasing marginal utility. The notion is supported by several meta-analyses of ecosystem and non-market valuation. Ghermandi et al. (2010) in their extensive valuation of natural and man-made wetlands, for example, find a negative relationship between wetland abundance and wetland value. The authors attribute this to a substitution effect, whereby people’s perceptions and preferences of one site are affected by the presence of alternative sites that may substitute some of the social and environmental services provided by that environment. Similarly, in their study on biodiversity values in forest ecosystems, Ojea et al. (2010) find that the provision of additional forest hectares results in a significant marginal decreasing utility, where a 1% increase in forest area leads to a 0.59% decrease in forest marginal value. The hypothesis is also supported by Schild et al. (2018), in their meta-analysis on the monetary valuation of dryland ecosystem services the authors find that the larger the selected study extent, the lower the resulting estimated ecosystem service.

The application of the EP may offer a solution to these problems, since the value per hectare of these ecosystems may be lower than might otherwise be expected from an ecological perspective, the associated discount rate will also be smaller, allowing for a re-balance in the value of the natural site compared with its development counterpart. This can be justified from a biological and ecological standpoint also, since rigorous economic assessment would require us to adress issues related to non-linearity, threshold effects, spatial variability and irreversible damages (Bagstad et al., 2014).

The main limitation of this study relates instead to the availability of market data on development lands. While for most cases data on adjacent development lands within similar district or provincial jurisdictions was available, for some countries market prices for development land were found only for specific urban areas or capital cities. This can be problematic since the EP should ideally be applied using land values with similar environmental characteristics and within the same local jurisdiction. Moreover, land prices from capital cities will probably be among the highest within each country, which will subsequently lead to lower discount rates than we might otherwise expect. For example, in the case of Sweden, TEV values of €4-20/ha/year (Table 6) were obtained from an assessment of ecosystem services in the County of Vasterbotten, while prices for residential and industrial land were representative of Stockholm. As a result of the generally low TEV values of the natural sites and the high market prices for development land in the capital, discount rates for Sweden were estimated at 0.0% on average (Table 9).

Nevertheless, the discount rates presented here are not intended to be prescriptive. Instead, the purpose of this study is to show how the EP might apply in different societal and contextual settings. Accounting for the strong heterogeneity of the data related to land-use, scale and representativeness of sites for each country would help consolidate results to some degree, however undertaking a serious comparison among countries would rely on more robust site-specific information on the market prices of land designated for development, social preferences about natural sites, as well as decision-making affecting territorial planning. Indeed, these factors have strong geographical implications that will vary among and within each country, and will mean that discount rates can be expected to differ considerably according to each site. The key contribution of this work is therefore to show that the EP can be employed in completely different contexts, moving towards the definition of different "Equivalency Principles".

3.5. Conclusion

With discount rates ranging between 0% and 11%, and averaging 1% across countries, the EP has been demonstrated as an alternative policy tool for incentivising the protection of natural lands within territorial planning and decision-making. In line with our aforementioned hypothesis, the EP results in discount rates that are geographically differentiated and that vary according to habitat and social preferences over natural and development land types. Consequently, the EP offers a new way of guaranteeing sustainable land-use in the long-term, taking into account the many dimensions of sustainable development, including: economics, society, institutions and the environment. Moreover, the EP can provide an important, and often unconsidered, dimension to decision-making particularly in the case of climate change where the threat of catastrophic impacts and environmental degradation may cause irreversible damages in the future. Subsequently, the EP may be used within policy development, particularly in land and urban planning decision-making contexts, for addressing increasing scarcity of natural resources, by balancing economic and environmental objectives, and capturing a more considered value of natural resources and their intrinsic worth to both current and future generations.

The EP is particularly relevant for adaptation decision-making, which has been largely structured by economic objectives set forth by institutions and political processes without recognising the wider cultural and context-specific ramifications of policy choices. Further research in this area would benefit from a more in-depth insight into social preferences over natural sites as well as locally-specific factors affecting sustainable land-use practices and decision-making, which will improve the theoretical and practical underpinnings of the principle.

Chapter 4: Accounting for the effects of employment, equity and risk aversion in cost-benefit analysis – An application to an adaptation project

4.1. 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 (Markanday et al., 2019). Able to compare various measures over time, CBA permits the evaluation of adaptation pathways[20] 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[21]). If the NPV is negative, it means that costs supersede 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) when a discount rate is applied[22] (r) (see Equation 4).

$$\text{NPV} = \sum_{t=1}^{T} \frac{\text{B}-\text{C}_t}{(1+r)^t} \tag{4}$$

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

[20] 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 (CoastAdapt, 2017)

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

[22] 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 favoured over those with more long-term benefits

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 for example: Ackerman and Heinzerling, 2001; 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 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[23]. 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 and 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 (that is, 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 that arises from environmental CBA 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

[23] For further information, see Markandya and Richardson (2017)

(Chiabai et al., 2013). Using high positive rates (e.g. market rates) can trivialise catastrophic events 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 (2001) 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 (Dasgupta, 2007; Stern, 2007; Weitzman, 2009), or declining rates (Cropper and Laibson, 1998; Gollier, 2008; Groom, 2014; Philibert, 2006) to be used instead.

Scientific discourse on environmental CBA has predominantly centred 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 in this paper that there are three (often neglected) dimensions of CBA that require proper attention in the context decision-making on climate change change adaptation. The first relates to the consideration employment effects. Investments in adaptation could have direct and induced positive effects on the labour market by, for example; directly creating jobs, facilitating the creation of jobs, or improving labour supply. This is particularly important when considering labour markets 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 labour market, such as involuntary unemployment, do not exist (Bartik 2012; Masur and Posner 2012). This implies that any additional labour 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 labour) and non-work (based on the subjective value of time) activities are both equal to the market wage, and the cost of project labour is also equal to the market wage, then workers would not gain from additional employment. The cost of project labour 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 labour markets, since any benefits arising from additional employment would be offset by higher labour 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 labour 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 labour 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 are distributed among those affected by the project). CBA deals with effects on well-being by parsing monetary equivalents, i.e. how much individuals are willing to pay (WTP) for policies that benefit them or how much they are willing to accept (WTA) for policies that disadvantage them. By focusing on aggregate benefit, CBA automatically favours policies with a positive sum of monetary equivalents, irrespective of how benefits are distributed. This becomes especially problematic when deciding between policies or programmes 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 and 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 organisational structures for carrying out this objective. Taking into account the distributional consequences of climate-related decision-making is important since 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 (Sainz de 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 and Patz, 2015). Adaptation decisions can achieve 'equity in outcome' by recognising 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 and 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 whilst also safeguarding fairness and equity objectives within climate change decision-making.

A 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 unfavourable 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). 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 dimensions into CBA. Section 4.3 will go on to discuss the main findings, before finishing with concluding remarks in Section 4.4.

4.2. Materials and methods

To demonstrate the sensitivity of climate change decision-making to the effects of employment, equity and risk aversion, this study assesses the economic efficiency of an adaptation investment project by conducting a cost-benefit analysis based on four different 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.

4.2.1. 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, 2019). Due to its hilly terrain, steep valleys, high levels of rainfall, and densely urbanised 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 (Fig. 11). In 2012, concerns were raised by the Basque Water Agency (URA) when a new urban district was proposed to be built on the Zorrotzaure peninsula, an old industrial site at severe risk of flooding. In light of this, the city proposed opening and widening the adjoining Deusto canal, turning Zorrotzaure into an island (Fig. 12). The proposed measure has been designed to improve the drainage capacity of the Bilbao Estuary by opening and widening the width of the canal to 75 metres, thereby significantly reducing the risk of flooding in the urban district and neighbouring areas further upstream. Construction of the project began in 2014[24] and is expected to reduce the water level by up to 1.43 metres in some areas, with an estimated cost to the city of €20.9 million (Climate-ADAPT 2016). Considering a 100-year return period under emission scenario RCP4.5, damages are expected to be reduced by between 67.42% (lower bound estimate) and 65.93% (upper bound estimate) with avoided damages expected to reach between €289.43 and €347.23 million by the year 2080 (Basque Government 2007; Osés-Eraso, Foudi, and Galarraga 2012), with corresponding benefits in the intervening years. These estimates represent lower bound and upper bound estimates, calculated as the difference in damages with and without the opening of the Deusto canal (Table 12). See endnotes for an explanation on how these values were calculated[i].

[24] Zorrotzaure 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

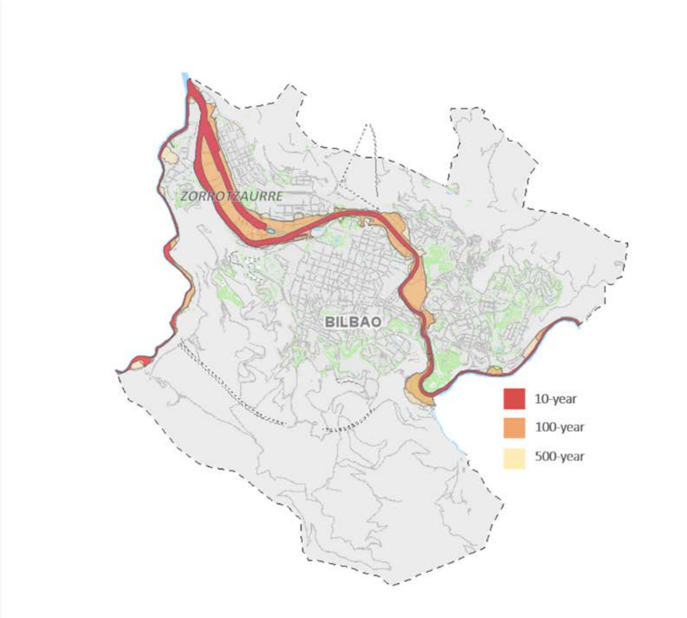


Figure 11. Flood risk in the city of Bilbao from 10-year, 100-year and 500-year flood events (source: GeoEuskadi data portal)

Table 12. 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 the Duesto canal)	429.29	526.67
Climate change scenario (with the opening of the Duesto canal)	139.86	179.44
Total benefits*	289.43	347.23

Figure 12. The proposed urban island of Zorrotzaurre

4.2.2. 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 four years while construction was underway (2014-2020). We assume that benefits only start accruing from the year 2018, once construction was complete and the adaptation functional. We estimate an annual benefit value for 2018 by considering the economic growth expected to take place in the region between 2018 and 2080. Economic growth rates for the European Union under SSP2[25] are applied to the years preceding 2080[26]. 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 (Crespo Cuaresma 2017; Leimbach et al. 2017; Riahi et al. 2017). This gives us an annual benefit value of €109.44[27] million for the year 2018. Benefits for 2018 and 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%).

[25] 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

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

[27] This is considering the lower bound benefit estimate of €289.43 million for the year 2080

4.2.3. 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 can be measured based on the shadow wage rate (SWR), (often synonymous with the social opportunity cost of labour). The SWR refers to the loss of other labour 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 an alternative job to a job in the new project. As it stands, the literature on CBA offers different formulas for deriving the SWR (Brent, 1991; Cowell and Gardiner, 2000; Dasgupta and Pearce, 1972; Drèze and Stern, 1987; Johansson-Stenman, 2005; Lewis, 1954; Little and Mirrlees, 1974; Marchand et al., 1984; Marglin and Sen, 1972; Roberts, 1982) based on different assumptions to do with labour (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 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 labour 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 labour market conditions): i) fairly socially efficient; ii) quasi-Keynesian unemployment; iii) urban labour dualism, and; iv) rural labour dualism. The Basque region is classified as having a fairly socially efficient labour market, with a relatively high-income level, 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 labour 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 labour 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 (Fig. 13)[28]. 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 (0.94) 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 Bizkaia) then the adjusted

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

conversion factor would be 0.79. We apply the approximation that the total investment costs for the project are composed of 60 percent capital costs and 40 percent labour costs, then adjust labour costs by applying the calculated conversion factor of 0.79. This results in a reduction in total costs compared to the previous scenario.

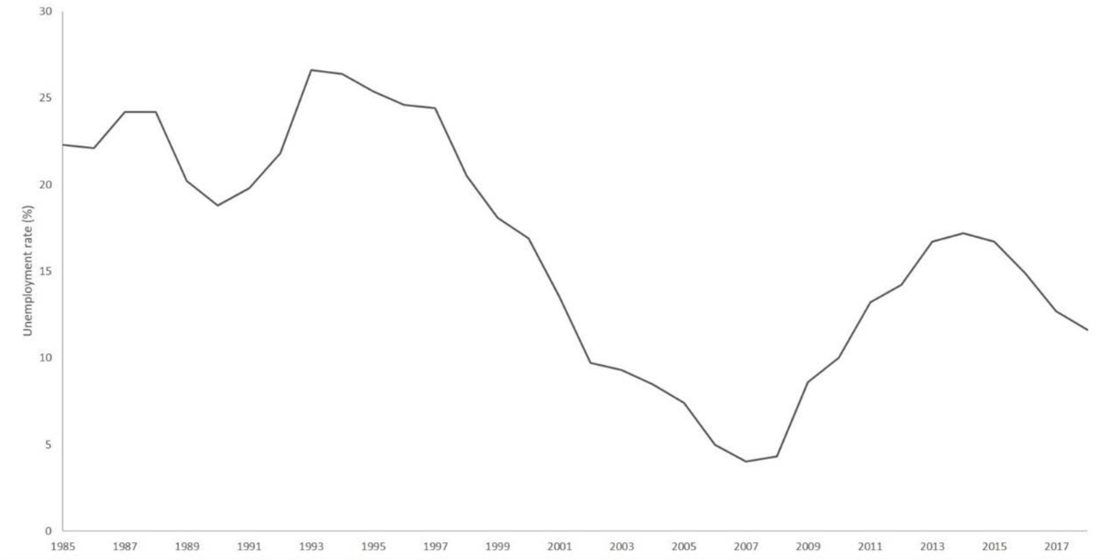


Figure 13. Annual unemployment rates for the Bizkaia province of the Basque Country (1985-2018)

4.2.4. Scenario III: standard CBA including employment and equity

Scenario III adds a second dimension to the CBA, that is, whether the benefits of the adaptation are equitably distributed among those affected by the project. Monetary equivalents (of benefits) are adjusted by applying different 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 and Van der Tak, 1975) its inclusion in CBA diminished by the 1990swhen concerns about income distribution declined. Some also criticised the approach based on the uncertainty of (the elasticity of social marginal utility of income). But values for derived from government social policies have since been proposed, with typical rates ranging between 1 and 2 (Atkinson 1970; Gouveia and Strauss 1994; Lambert, Millimet, and Slottje 2003; Stern 1977; Young 1990). Broadly speaking, the evidence suggests that on the whole, the value of one additional Euro is worth twice as much to a person earning €1,000 than to a person earning €2,000 due to decreasing marginal returns (H. M. Treasury 2003).

Distributional weights for different neighbourhoods (with different income bands) are calculated based on the following social welfare function (Atkinson 1970):

$$W = \sum_{i=1}^{N} \frac{AY_i^{1-\varepsilon}}{1-\varepsilon} \tag{5}$$

Where:

W = Social welfare function

Y_i = Income of individual i

ε = Elasticity of social marginal utility of income or inequality aversion parameter

A = Constant

If the social marginal utility utility of income is defined as:

$$\frac{\partial W}{\partial Y_i} = AY_i^{-\varepsilon} \tag{6}$$

And,

$$\frac{\partial W}{\partial Y_i} = SMU_i = \left[\frac{\bar{Y}}{Y_i}\right]^{\varepsilon} \tag{7}$$

Assuming a population with an average income of €20,000[29] per annum in Bilbao, we derive distributional weights for different income bands using elasticities of 1 and 2 (see table 13 for an example). Using a conversion factor based on the ratio between the expected weighted benefits and expected unweighted benefits, values can then be adjusted for each year 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 and €1.07 million compared to €1.09 million (unweighted) when elasticities of 1 and 2 are considered, respectively. In this scenario, while costs would remain unchanged, the benefits of the project would decrease compared to the previous scenario.

[29] The actual figure used is €21,245 (EUSTAT, 2018b)

Table 13. Relationship between income level, distributional weight and cost

Income (EUR)	Distributional weights	
	$\varepsilon = 1$	$\varepsilon = 2$
5,000	4	16
10,000	2	4
20,000	1	1
50,000	0.4	0.16
100,000	0.2	0.04

4.2.5. Scenario IV: standard CBA including employment, equity and risk aversion

For this scenario, 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. By estimating this certainty effect, we can generate a risk-ratio for each year that compares the expected cost of a flood event for an individual in a risk-averse versus a risk-neutral society. Taking the year 2018 as an example, let us consider a case wherein individuals maximise expected utility, given as:

$$EU = 0.99 \times U(21{,}245) + 0.01 \times U(21{,}245 - 5{,}088) \quad (8)$$

That is, the probability of a flood event not occurring for that year (99%) multiplied by the average income per person plus the probability of a flood event occurring that year (1%) multiplied by average income minus the estimated loss per person. The estimated loss per person is calculated as the damage from a 100-year flood event in that year (€109 million) divided by the affected population (21,422).

If the certainty equivalent, denoted as Y^*, is:

$$U(Y^*) = EU \quad (9)$$

Then the true loss, including loss due to risk, is given by:

$$0.99 \times 19{,}647 + 0.01 \times 16{,}157 = Y^* \quad (10)$$

If society is risk-averse, then we assume a concave utility function such as, for example, when $U(x) = \ln(x)$ gives us the following:

$$EU = 0.99 \times 9.96 + 0.01 \times 9.69 = 9.96 \quad (11)$$

This allows us to calculate Y* as:

$$Y^* = e^{9.96} = 21{,}187 \quad (12)$$

This is a special case of concave utility functions of the form:

$$U(x) = \frac{x^{1-\eta} - 1}{1-\eta} \quad (13)$$

These functions exhibit what is called constant relative risk aversion, given by the value of η. When η is set equal to 1, then the function reduces by L'Hôpital's Rule to:

$$U(x) = \lim_{n \to 1} \frac{x^{1-\eta}}{1-\eta} = \ln x \quad (14)$$

The risk-adjusted cost of the event accounting for the certainty effect is calculated to be €58.09[30]. If the expected loss per person in 2018 is €50.88 (estimated as the real income minus expected income) then the risk ratio for this year would be 1.142 $\left(\frac{58.09}{50.88}\right)$ and the adjusted benefits in 2018 accounting for risk aversion would be €1,244,307[31]. This ratio is calculated calculated for each year and used to adjust expected benefits in 2018 and 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. When constant relative risk

[30] This is the expected loss per person in 2018 (€50.88) plus the expected utility (€21,194) minus Y* (€21,187)

[31] 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 do not have this data available to us. 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 of risk aversion could apply.

aversion is not assumed, then the extent of risk aversion can be adjusted by altering η, wherein the higher the value of η the more risk averse individuals are assumed to be.

4.3. Results and discussion

The results of the CBA of the adaptation investment for the different scenarios are shown in Table 14. 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 implemented. Equally, an Internal Rate of Return (IRR)[32] 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 labour 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 labour 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.

Table 14. 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

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

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 neighbourhoods have incomes higher than the average of Bilbao, these regions are home to around 70% of beneficiaries (Appendix IX). Since benefits are not equitably distributed among affected groups, the adaptation is considered less efficient as a result. In this case, investors might 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 (Fig. 14).

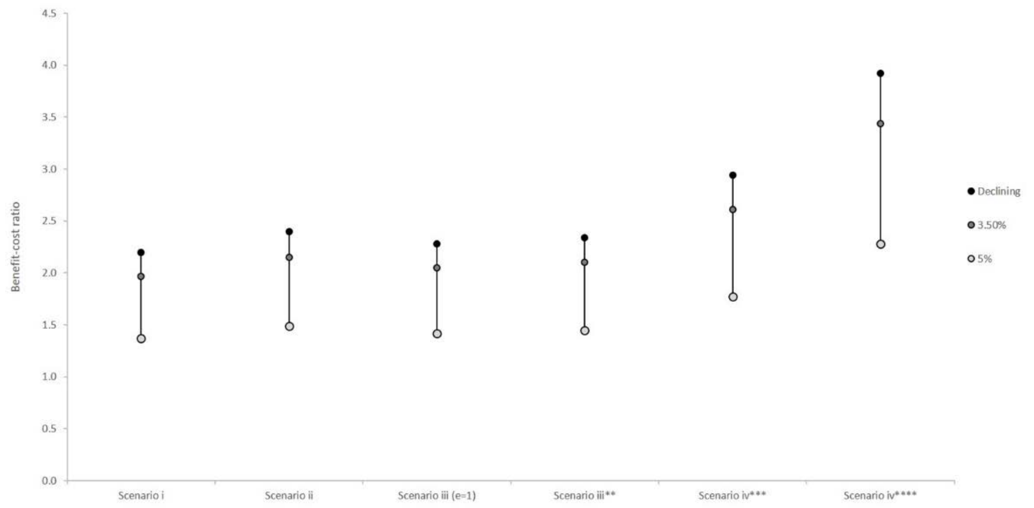


Figure 14. Sensitivity to discount rates (all scenarios), elasticity of income (scenario III) and extent of relative risk aversion (scenario IV)
* = 1, ** = 2, *** $\eta = 1$, **** $\eta = 2$

It is important to acknowledge here the growing evidence-base that highlights the disproportionate impact that climate change has on poor and marginalised 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[33], then the BCR would increase from 2.05 to 3.36 (considering an

[33] In this case, the San Francisco neighbourhood in Bilbao represents the lowest affected income group, with an average wage in this area of €13,637 (Appendix IX)

elasticity of 1) (Table 15). In contrast, when we consider the highest affected income band[34] 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.

Table 15. 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*	3.36	5.23
Highest affected income band*	1.27	0.75

Note: *refer to Appendix I for a breakdown of beneficiaries and income groups affected by the adaptation project

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 (Fig. 14). 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 (Treasury, 2018) were compared to the base discount rate of 3.5% (Fig. 14). 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 14). Since all costs are distributed within the first four 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 recognised. 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.

[34] In this case, the Abando neighbourhood in Bilbao represents the highest affected income group, with an average wage in this area of €35,944 (Appendix IX)

4.4. 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 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.

Chapter 5: The power of impact framing and experience for determining acceptable levels of climate change induced flood risk – A lab experiment

5.1. Introduction

The multifaceted and complex nature of climate change has meant that current models of future climate impacts are largely probabilistic and involve varying degrees of uncertainty (Refsgaard et al., 2007). Scientists warn us about the potential likelihood of catastrophic climate events, such as extreme floods, heat waves, and drought. These risks are, however, difficult for decision-makers to interpret, and in many cases they are underestimated (Galarraga et al., 2018). Several studies have stressed that underestimating climate risks may increase the risk of ineffective adaptation or maladaptation, doing little to relieve existing vulnerabilities and in some cases worsening them (Camerer and Kunreuther, 1989; Galarraga et al., 2018; Weitzman, 2009). Translating these complex risks into transformative action requires making the science accessible, comprehensible and useful for decision-makers. This means decoding highly technical scientific content into concise, effective messages targeted at broad audiences with different cognitive and analytical capabilities, such as policymakers and citizens. A deeper exploration of the cognitive drivers of action is needed in this respect, since current risk communication efforts have not been particularly effective in engaging and mobilising the public in a meaningful way, or in inciting the necessary and urgent political action needed at varying levels of governance.

5.1.1. Theories and concepts

Since the 1940's, the economic theory of human behaviour has focused primarily on the notion of the 'rational actor'. John von Neumann and Oskar Morgenstern showed that when certain axioms of rationality were satisfied, individuals faced with a set of risky choices with uncertain prospects would make decisions to maximize their utility (von Neumann and Morgenstern, 1947). The basis of rationality was strongly founded on the assumption that the main aim of all actors in an economic system, be it consumers or entrepreneurs, is economic gain (money or equivalent monetary commodities). When behavioural game theory was used to study the concept of utility maximisation and rationality among players in economic experiments, studies showed that choices were not always rational or utility maximising (Camerer, 2011). Many therefore began to question the descriptive inadequacies of the utility maximisation problem, and Simon (1956) would later orient the field toward decision models based on the concept of 'bounded rationality', positing that the rationality of individuals is limited by factors such as the information available to them, the cognitive limitations of their minds, and the limited time they have to make decisions.

Works by Tversky and Kahneman (1979) and Kahneman et al. (1982) built on this concept, avowing that boundedly rational individuals use mental shortcuts (otherwise known as heuristics), such as availability, representativeness, and anchoring for making decisions. Subsequently, many researchers became interested in the cognitive elements of decision-making, but little importance was placed on the influence of affect on decisions. It was not until much later, when Epstein (1994) began forming the foundations of what are today known as "dual-process theories", that affect began to be recognised as a central element of thinking, knowing and information processing (Chaiken and Trope, 1999; Kahneman and Frederick, 2002; Sloman, 1996). Dual-process theories postulate that humans use two distinct systems for information processing and decision-making, one non-experiential and the other experiential. The non-experiential system uses algorithms and normative rules for creating logical arguments and conducting assessments of risk and probability. The experiential system instead, is fast and intuitive, affect-driven and mostly automatic.

Epstein labelled the non-experiential system as "rational", but Slovic (2004) later renamed this mode of thinking as "analytic" instead, arguing that there are strong elements of rationality in both systems. Slovic reasons that the analytic system was developed later in human evolution, but it was the experiential system that first taught humans the basic survival mechanisms for responding to risk, by linking experience to emotion and affect, and helping to distinguish between good and bad decisions. The term risk-as-feeling was coined by Slovic to describe the use of affect and intuition in guiding decisions over certain risks, i.e. judging whether it is safe to walk down a dark street or to drink strange-smelling water. Some advocates of formal risk analysis still see affective responses to risk as irrational, arguing the disparity between expert assessments of real risks, which are objective, analytic and wise, and public perceptions of risk, which are subjective, often hypothetical, and emotional.

Despite these differences, Slovic maintains that risk assessment needs to address the dichotomy between these two judgements. If the main objective of risk communication is to motivate the public to act, then it should focus on the more subjective public reasoning of risk, rather than objective expert descriptions of "risk statistics", which he argues often does little to change people's attitudes and perceptions. Of course, risk analysis is meant for objectively defining the problem, setting exposure parameters to determine those at risk and developing metrics to best measure that risk. Risk communication, on the other hand, should deal with how to frame that risk, that is, how to present information to the decision-makers in a way that motivates them to act. Indeed, numerous studies have shown that different presentations of objectively equivalent descriptions of the same risk information can lead to different evaluations and decisions. What Slovic calls the risk game, he argues is essentially an exercise in power, wherein whoever controls the definition of risk controls the rational solution to the problem at hand. How one chooses to define risk, will determine how preferences are ordered and which action presents itself as the most cost-effective, or the most protective, or the best.

Roeser (2012, 2010), whose work draws on insights from the ethics of risk and the philosophy of emotions, goes one step further to say that this so-called exercise in power is not just about activating superfluous emotions, but should rather be seen as a necessary trigger for understanding the moral impact of risks, such as those related to climate change, which paradigmatically provide motivation. As Roeser (2012) states, the dominant, technocratic approaches to risk lack normative-ethical dimensions that are fundamental to decision-making on acceptable risk. Communication methods that appeal to emotions when it comes to moral decision-making might be an important missing constituent here. Rather than being reduced to a manipulation or nudge, provoking ethical reflection and deliberation could be the key to a different form of decision-making based on practical rationality (composed of both logical and emotional reasoning). Roeser argues that in the context of climate change communication, moral emotions should be integrated for two reasons. The first is that moral emotions can enable us to have more substantiated moral insights about climate change, and the second is that they can provide the motivation to change our behaviour in response to climate change.

Studies have shown that individuals may be lacking a sense of personal and emotional involvement with the anticipated impacts of climate change, thus reducing motivation to take action (Lorenzoni et al., 2007; Lorenzoni and Pidgeon, 2006). This signals a need to better understand public perceptions of risks, which may be sensitive to technical, social and psychological qualities of hazards that are not well modelled in technical risk assessments. Qualities such as uncertainty in risk assessments, feelings (i.e. of dread and fear) of being exposed to risks that are not under one's control, and perceived inequity in the distribution of risks, could all be important dimensions of public risk perceptions. A study conducted by Slovic (2010) showed that donations for starving children in Africa increase when compassion is invoked by a picture of one starving child, but decrease when the picture is accompanied by statistical information about the millions of needy children in similar situations across the country. As Slovic puts it, "people don't ignore mass killings because they lack compassion. Psychological research suggests it's the grim statistics themselves that paralyse us into inaction" (Slovic et al., 2007). In the same way, statistical information about climate change may (in most cases) be too abstract and devoid of meaning, overwhelming us with the idea that our efforts are futile and will make little difference.

Despite these insights, risk communication efforts have largely centred around fear arousal for motivating action. Dating back to the 1970s, Protection Motivation Theory tells us that there are three essential components to a fear appeal: a) the magnitude of harm related to an event, b) the probability of that event occurring, and c) the efficacy of a coping response (Rogers, 1975). It is generally understood that the extent of fear arousal will depend on how decision-makers judge these three components. The higher the level of fear arousal, the more persuasive the message will be at provoking higher levels of interest, and at increasing perceptions of threat severity, vulnerability and concern, subsequently encouraging attitudinal and behavioural changes.

Many studies have evidenced the relationship between negative affect and increasing perceptions of climate risk (Cooper and Nisbet, 2016; Leiserowitz, 2006; Otieno et al., 2014; Smith and Leiserowitz, 2012; Spence and Pidgeon, 2010; Terpstra, 2011; van der Linden, 2014). Recent research however, suggests that protection motivation may more complex than this, demonstrating that how we choose to describe or characterise climate change can trigger different intuitive, emotional and cognitive judgements, leading to different action responses. Studies have shown for instance, that reducing the psychological distance of climate change, describing it as a local rather than distant issue, can cause emotional responses and analytic appraisals that make it more personally relevant, thereby increasing motivation to act (Brügger and Pidgeon, 2018; Reser et al., 2014; Shih and Lin, 2017). Slight deviations in wording or visual stimuli have been shown to motivate individuals to act through distinct emotions, complex feelings such as empathy and hope may drive decisions for one set of individuals, while another may be driven to act through feelings of worry and guilt (Swim and Bloodhart, 2015). Different types of affective judgement have been found to influence individual risk tendencies, and can even act to amplify or dampen the effect of different risk framings (Druckman and McDermott, 2008). Subsequently, many have stressed the importance of focusing on discrete emotions when studying risk behaviour, which may be stronger predictors of action responses and policy support than negative affect alone (Smith and Leiserowitz, 2014).

5.1.2. Flood risk communication

One of the most pressing areas of climate risk research relates to the communication and management of flood risks. The disparity between expert and citizen assessments of risks has resulted in a deficit model of public (mis)understanding, prompting risk managers to search for design features that best communicate flood risk information (Demeritt and Nobert, 2014). Studies have shown that communication devices such as risk maps and other information sources tend to be ignored, with those at risk often underestimating their exposure and vulnerability (Bubeck et al., 2012; Burningham et al., 2008; Harvatt et al., 2011). Factors such as personal experience of flood events have been shown to increase the perceived salience and response to risk communications (Kellens et al., 2011; Lawrence et al., 2014), but questions arise as to whether responses are based on transient emotions or conducive to long-term behavioural changes, and how best to foster this within communications remains a challenge.

The effect of experience has signalled a need for communications that focus not only on the technical aspects of risk, but also on aspects that help to arouse emotional connections that increase personal engagement with the issue. A further challenge relates to the communication of numerical descriptors, such as the uncertainties, impacts and probabilities associated with flood risk. Many studies point to the cognitive challenges associated with decoding commonly used flood descriptors such as the '100-year flood' (Bell and Tobin, 2007; Highfield et al., 2013) and probabilities involved in precipitation forecasts (Gigerenzer et al., 2005). However, there is insufficient evidence to say how such complexities in information may impede decision-making. Finding the right balance between analytical and emotional components of flood risk communications may be a key missing constituent for motivating precautionary behaviour.

The remainder of this paper will focus on how various framings of flood risks may evoke different types of cognitive and emotional reasoning, which in turn may act to motivate or inhibit precautionary behaviour related to climate change induced flooding. The following section will describe in detail the research questions and hypotheses. After which, Section 5.2 will provide a description of methods and study design. Section 5.3 will explore the analysis and results, followed by a discussion of results and policy implications in Section 5.4, and concluding remarks in Section 5.5.

5.1.3. Current study

In order to assess how different climate change risk framings evoke different cognitive and affective responses when processing risk information, and subsequently lead to different action responses, an empirical assessment is conducted based on the following research questions:

1. Does a climate change risk frame that includes a photo of climate impacts (compared to a text-only frame), evoke greater affective reasoning, leading to lower levels of risk acceptability?
2. Does a climate change risk frame that presents economic impacts as range (compared a single-value frame), arouse greater objective reasoning, leading to higher levels of risk acceptability?

To help answer these questions, the following research hypotheses have been developed:

H1A: visual representations of climate change impacts trigger availability heuristics – that is, individuals will recall past information, experiences, and narratives on climate change enabling a moral assessment of risk acceptability. This frame is also expected to trigger affect heuristics that stimulate higher levels of concern and negative affective responses, leading to higher perceptions of threat and lower levels of risk acceptability.

H1B: more complex risk information (economic impacts framed as a range of values compared to a single-value) will subdue the affective reasoning caused by the photo by inducing more objective and analytical forms of information processing.

H2: assessments of risk acceptability depend on the complexity of risk information. More complex risk information (economic impacts framed as a range rather than a single-value) will evoke more objective and analytical forms of information processing that are more emotionally detached, leading to higher appraisals of risk acceptability.

In order to distinguish between affective appraisals of risk based on moral reasoning (contemplation of long-lasting narratives of the problem at hand), which are more practically rational, and affective responses to risk that are reactive or 'gut' based, which may be more error-prone and irrational, a third research question was developed:

3. Is decision-making immediately after experiencing climate impacts (in terms of economic losses) more reactive or 'gut' based, leading to less rational perceptions of threat and differences in valuations of risk acceptability?

To test the third research question we develop one more research hypothesis:

H3: Experiencing climate impacts prompts higher and less analytical perceptions of threat. That is to say, if the objective description of risk information remains unchanged (the risk itself is neither higher nor lower), directly experiencing a loss will lead to a perceived change in risk. Changes in risk perception, in conjunction with a trial and error heuristic, will lead to adjustments in subsequent decision-making intended to correct for past mistakes or failures. In the case of experiencing impacts therefore, heightened perceptions of risk will induce lower appraisals of risk acceptability and subsequently, differences in action responses. If climate impacts are not experienced, then familiarity with the problem (knowing the outcome and repeating the decision) will instil a rationale that circumstances directing past decisions still hold true and that past behaviour can be successfully applied to new situations. Thus, for participants who do not experience damages risk perceptions will remain unchanged, leading to similar appraisals in risk acceptability and action responses in later decisions.

5.2. Materials and methods

A three-part economic lab experiment was designed to explore the three research questions, comprising: 1) a risk-elicitation task to measure individual based risk preferences, 2) a role-playing exercise to measure climate change risk acceptability and action responses based on different risk framings and experience, and 3) a post-experiment survey to assess differences in cognitive and affective reasoning, as well as other potential moderating factors, such as socio-demographic effects pertaining to age, gender, nationality and education.

5.2.1. Measures

Risk propensity

Risk preferences (that is, general levels of risk aversion) were measured using the well-established risk-elicitation task developed by Falk et al. (2016). The exercise follows a staircase risk procedure for determining risk preferences, asking participants to make five interdependent choices between a lottery and a sure payment. While the lottery stays the same in all decisions, the sure payment is adjusted after each decision depending on how risk-averse or risk-taking participants are in previous decisions. Risk scores between 1 (very risk-averse) and 31 (very risk-taking) are calculated for each participant based on their implied switching row, that is, the point at which the sure payment is preferred to the lottery.

Risk acceptability

A role-playing exercise was designed to simulate a situation wherein a policymaker is responsible for a coastal town at risk of flooding. To reduce the potential for hypothetical bias, participants are asked to assume responsibility for the local Basque coastal town of Zarautz, an area at risk of extreme storm events and coastal flooding that has suffered flood related damages in the near past[35]. The policymaker must assess the risks they face, that is, the probability of a flood event occurring, the economic losses they would suffer in the case of an event, and how much they would be willing to invest to protect their town and reduce their risk from future flood damage. A 2x2 between-subject design was designed to study the effect of visual (photo vs. text-only) and economic impact (range vs. single-value) framings on appraisals of risk acceptability. In addition to general background information on their town, the policymakers are given information from their advisors informing them of the potential risks they face from flooding. In the message from their advisors, policymakers are shown one of two descriptions of the economic impact – an average economic loss represented as a single-value, or a range of economic losses, represented as a low and high value. The probability of a flood event occurring and the expected losses from flooding are equivalent in both conditions. The policymakers are then either shown a photo of damages from a previous flood event that occurred in their town along with a text describing the event, or they are shown only the text.

[35] Flooding represents one of the major climate related impacts in the North of Spain, especially impacting the Basque Country (Gobierno Vasco, 2015)

Potential flood-protection solutions are then described to the participants, with increased protection heights corresponding to increased investment costs. A table of options is shown to participants summarising their options: the more they are willing to invest in protection, the lower their risk of incurring economic damage from a flood event. The table contains 19 options ranging from no protection (95% chance of suffering economic damage) to maximum protection (5% chance of suffering economic damage). In conditions where the economic damage is framed as a range, the probability of flood damage is distributed between a low damage event (small loss, high probability) and a high damage event (big loss, low probability), whereas in conditions where the economic damage is framed as a single-value, the probability of flood damage is concentrated on a single average loss. Expected losses remain the same in both conditions. The list of options was designed such that each incremental increase in investment results in a 5% decrease in the probability of incurring economic losses from flooding.

In order to make it more credible to participants that the likelihood of experiencing flooding impacts is based purely on chance, participants are told that the outcome of their decisions as policymakers is dependent on the rolling of a 20-sided die. For each option, a given number on the die would mean that they either experience a flood event and suffer economic losses, or that they have managed to protect their town and suffer no losses as a result. Once participants have decided on an option (how much they would like to invest in protection), they roll a computerised die that randomly generates a number between 1 and 20. Depending on their chosen option, the generated number represents whether or not they have managed to protect their town. Levels of risk acceptability are determined by the amount invested in protection, with option 1 representing a very high level of risk acceptability (no motivation to be risk reducing, with no investment in protection), and option 19 representing a very low level of risk acceptability (high motivation to be risk reducing, with maximum investment in protection).

Experience

Participants are asked to make investment decisions at two decision points: period 1 and period 2. All 19 flood protection options, their costs, flood probabilities and damage costs remain the same across the two periods. Once participants have selected an option and discovered their outcome for period 1 (whether or not they have managed to protect the coast), they are asked to make the same decision again for period 2. Participants are instructed to assume that all protection has been stripped from the coast between the two periods, so that they are making the same decision again, with the only difference being the experience they have gained from period 1. The change in risk acceptability between period 1 and period 2 is used as a measure of the impact of experience. The difference in values is compared between those that suffer economic losses and those that do not between the two decision points.

Affect, concern and responsibility

The well-established positive and negative affect scales developed by Watson et al. (1988) are used as a measure of participants' emotional reasoning. An 8-item scale was developed consisting of four negative affect items (fear, guilt, distress, nervousness), and four positive affect items (determination, interest, enthusiasm, empowerment). Participants are asked to rate to what extent they experienced these emotions during the experiment using a 5-point Likert scale. Scores for individual items, as well as grouped positive and negative affect scores, are assessed. In a separate item, participants are asked to rate, using a 5-point scale, how concerned they are about the impacts of climate change in Zarautz. Finally, as a measure of general climate change beliefs and moral responsibility, participants are asked to read and rate to what extent, again using a 5-point scale, they agree with the following statement:

"Climate change is happening and observed increases in greenhouse gas (GHG) pollution due to human activities are largely responsible. Over the 20th century, we have seen many changes such as rising global sea levels, extensive melting of snow and rises in global average air and ocean temperature. The consensus in the scientific community indicates if we reduce carbon pollution to an acceptable level the worst effects of climate change can be avoided. We are all responsible for this problem and the potential consequences for our future and next generations. Climate change is a major challenge that must be addressed by governments, industries, and individuals before it is too late to reverse the worse projected scenarios. Doing something for climate change is a moral duty."

5.2.2. The sample

A computerised artefactual lab experiment was conducted at the University of the Basque Country in September 2018 on a representative sample of the population in Bilbao, Basque Country (Spain)[36]. The independent survey recruitment company CPS in Bilbao was used to capture a sample representative in terms of age, gender, social class, nationality and job type. The experiment was translated to and conducted in Spanish. One-hundred-sixty-one participants were recruited and randomly assigned to one of the four treatments. Each treatment group consisted of approximately 40 participants. Subjects were 51% female, 49% male and < 1% non-binary. Ages ranged from under 18 to over 65, with education levels of primary and secondary level up to university level. 80% of participants identified as Spanish, 12% as Basque, and 8% were from other nationalities. In order to simulate an environment wherein participants could experience real gains and losses, experimental tokens (€1 = 50 tokens) could be earned during the first two tasks (the risk elicitation task and the role playing exercise). Participants

[36] While the experiment focused on flood events in the neighbouring Basque town of Zarautz, the experiment itself was conducted in Bilbao where the closest economic laboratory was situated

could earn a maximum of 150 experimental tokens (or €3) during the first task and a maximum of 850 experimental tokens (or €17) during the second task.

5.3. Analysis and results

A series of Analyses of Variance (ANOVA) tests (Lindman, 1974) were conducted to test the hypotheses. In addition, an overall logistic regression analysis was used to assess the strength of predictor variables for understanding framing effects. All analyses were conducted using the statistical software package R.

5.3.1. Risk propensity

During the experiment several participants expressed an incomplete understanding of the risk-elicitation task. Some were unaware that the exercise involved making five consecutive decisions, and instead continued to click on their first choice (of lottery or sure payment) until the screen for the next task appeared. A chi-squared goodness-of-fit test confirmed that risk scores were not normally distributed, but instead followed a 3-peak distribution. Although risk-scores for a limited sample may indeed follow this type of distribution, because of the number of participants who expressed doubts about the task, we decided to omit this variable from further analysis. A screen placed in-between each choice-set indicating when a new decision should be made may help to prevent speeding issues like this from occurring.

5.3.2. Risk acceptability in response to visual and economic impact framings

Participants had lower levels of risk acceptability (i.e. invested significantly more in protection) when shown a photo of past flooding impacts in Zarautz compared to when only the text was shown ($F(1,159)=6.595$, p-value=0.011). The effect of the photo was stronger when economic impacts were framed as a single-value, compared to a range of values ($F(1,77)=0.573$, p-value=0.452). When compared to text-only conditions, participants in the photo conditions exhibited significantly greater negative affect responses related to feelings of guilt ($F(1,159)=4.411$, p-value=0.037) and fear ($F(1,159)=3.948$, p-value=0.048), demonstrated greater feelings of concern ($F(1,159)=14.78$, p-value=0.0002), and felt more of a sense moral responsibility ($F(1,159)=5.33$, p-value=0.022).

No significant difference in risk acceptability was detected between participants that saw economic impacts framed as a single-value or as a range of values (F(1,159)=0.447, p-value=0.505). Participants that saw economic impacts framed as a single-value however, were found to have greater feelings of guilt (F(1,159)=5.957, p-value=0.016) compared to those that saw economic impacts framed as a range. No significant difference in levels of concern (F(1,159)=0.395, p-value=0.531) or moral responsibility (F(1,159)=0.418, p-value=0.52) were detected between the two economic impact framings. As expected, task difficulty levels were higher when economic impacts were framed as a range of values (F(1,159)=4.33, p-value=0.039). Summary statistics for the various treatments are shown in Table 16.

Table 16. Summary statistics for visual and economic impact framings

	Visual framing:		*Economic impact framing:*	
	Photo	Text-only	Range	Single-value
Risk acceptability				
Investment P1	125.5 (45.36)	106.2 (49.99)	109.9 (49.99)	118.0 (46.95)
Cognitive effort				
Task difficulty	1.75 (0.96)	1.82 (0.98)	1.86 (0.99)	1.73 (0.95)
Concern & moral responsibility				
Concern	4.21 (0.99)	3.58 (1.09)	3.77 (1.07)	3.94 (1.08)
Moral responsibility	4.74 (0.65)	4.41 (1.05)	4.47 (0.98)	4.61 (0.82)
Positive Affect				
Determination	3.63 (1.23)	3.51 (1.29)	3.45 (1.22)	3.54 (1.24)
Interest	3.81 (1.16)	4.02 (0.97)	3.86 (1.10)	3.88 (1.12)
Enthusiasm	2.71 (1.27)	2.82 (1.72)	2.79 (1.28)	2.80 (1.23)
Empowerment	2.96 (1.33)	2.75 (1.27)	2.79 (1.24)	2.93 (1.28)
Negative Affect				
Fear	2.04 (1.27)	1.67 (1.10)	1.76 (1.13)	1.95 (1.23)
Guilt	1.99 (1.31)	1.60 (0.98)	1.61 (0.97)	1.89 (1.23)
Distress	1.99 (1.25)	2.24 (1.21)	2.15 (1.17)	2.05 (1.17)
Nervousness	1.96 (1.30)	1.95 (1.09)	1.99 (1.13)	1.97 (1.20)

Note: Values represent the mean with standard deviations in brackets

5.3.3. Risk acceptability in response to experience

A paired sample t-test was conducted to assess the impact of experience (suffering economic impacts or not between the two periods) on levels of risk acceptability. As hypothesised, participants who experienced economic impacts in Period 1 had lower levels of risk acceptability in Period 2 (p-value=0.007), whereas there was no difference in risk acceptability between periods for those who did not experience economic impacts (Figure 15a and 1b).

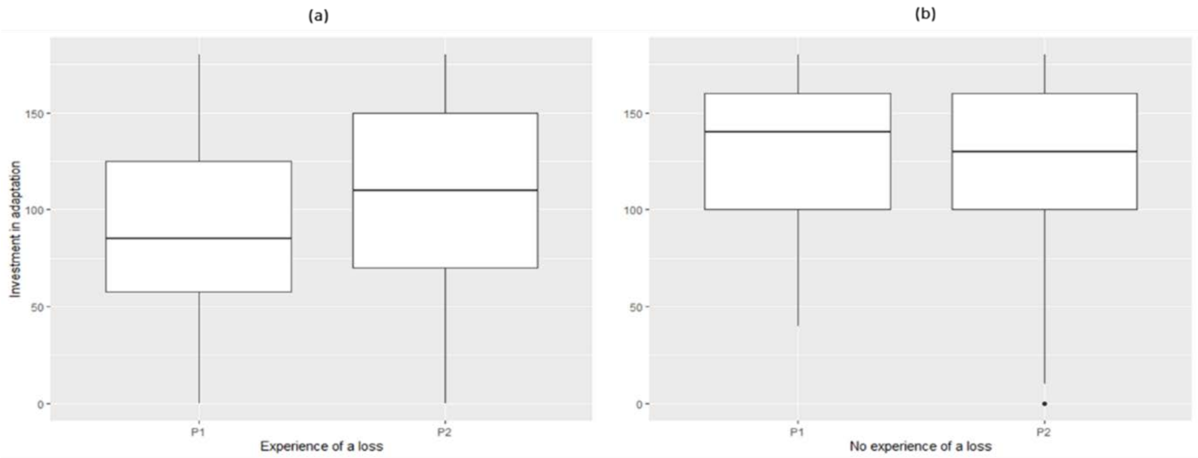


Figure 15. Investment in Period 1 and Period 2 for those that experienced a loss (a) and for those that did not (b) between the two periods

The regression model shown in Table 17 reveals that investment in Period 1 (initial level of risk acceptability) is a predictor of whether or not participants would experience economic losses (with those that invest more in protection being less likely to experience economic impacts), and subsequently, how much participants would invest in Period 2. Risk acceptability in Period 2 (denoted by investment) is largely dependent on what participants invested in Period 1, but for participants who did not experience losses between the two periods, risk acceptability in Period 2 is also driven largely by a sense of moral responsibility, and other affective responses such as concern and feelings of empowerment (Table 17, models 3 and 4).

Table 17. Regression analysis of factors driving experience and investment in Period 2

	Dependent variable:			
	Experience (loss=1, no loss=0)	Investment P2	Investment P2 (experience)	Investment P2 (no experience)
	(1)	(2)	(3)	(4)
Risk acceptability				
Investment P1	-0.005*** (0.001)	0.67*** (0.06)	0.67*** (0.12)	0.73*** (0.08)
Experience				
(loss=1, no loss=0)		4.93(6.42)		
Concern & moral responsibility				
Concern			3.99 (6.05)	-6.74** (3.31)
Moral responsibility			3.71 (7.68)	11.94*** (3.79)
Positive Affect				
Determination			-1.02 (5.83)	-4.21 (3.14)
Interest			12.17* (7.03)	-2.41 (3.47)
Enthusiasm			-7.39 (5.68)	-0.59 (3.04)
Empowerment			-1.43 (7.24)	5.77* (3.06)
Negative Affect				
Fear			-2.17 (6.18)	1.85 (3.47)
Guilt			1.04 (6.24)	2.62 (3.34)
Distress			4.48 (6.35)	2.36 (3.46)
Nervousness			-10.89 (7.31)	-4.40 (3.75)
Constant	0.91*** (0.09)	40.36*** (9.22)	10.05 (38.84)	7.82 (21.52)
Observations	161	161	60	101
R^2	0.22	0.45	0.49	0.51
Adjusted R^2	0.21	0.44	0.38	0.45
Residual Std. Error	0.43 (df=159)	34.86 (df=158)	42.89 (df=48)	28.73 (df=89)
F Statistic	44.10*** (df=1;159)	64.75*** (df=2;158)	4.25*** (df=11;48)	8.36*** (df=11;89)
Note:				*p<0.1; **p<0.05; ***p<0.01

5.3.4. Socio-demographics

While no difference in risk acceptability between men and women was found (F(1,158)=3.255, p-value=0.073), further ANOVA tests confirmed that women felt more interested (F(1,159)=14.3, p-value=0.0002), enthusiastic (F(1,158)=9.397, p-value=0.0026), and empowered (F(1,158)=9.659, p-value=0.0022) during the experiment compared to men.

5.4. Discussion

The results indicate that including a photo of impacts in climate change communications can be a strong motivator for encouraging action on climate change, driven by a sense of social or moral rationality and emotional reasoning. It seems that when subjects are visually reminded of the potential environmental or social devastation caused by climate change the problem becomes more personal, their moral judgment is guided by emotional responses, such as guilt and fear. This connects them with the issue and causes them to invest more in climate protection. Their concern about impacts in the region is higher, and they exhibit a stronger sense of personal duty and responsibility towards the issue of climate change compared to those exposed to other framings. These findings build on those of previous assessments that explore the effects of climate change imagery on personal engagement with the issue. Studies suggest that visual reminders of climate impacts, particularly those related to disasters and extreme events, are effective at promoting feelings of salience and emotional arousal (Leviston et al., 2014; O'Neill et al., 2013). However, fear-inducing imagery has also been linked to decreased feelings of efficacy and personal engagement with the issue of climate change (O'Neill and Smith, 2014). In light of this, some argue that positive imagery (i.e. of specific solutions and adaptations) may be more empowering and effective at encouraging behavioural responses (Braasch, 2013), but there is still insufficient evidence to back this claim. The fact that visual frames in this study were able to evoke fear as well as encouraging greater preparedness, may be due in part to the other supporting information provided to participants. Participants were given information about adaptation solutions, and the potential losses and probabilities of a flood event, which in combination with the photo, may have led to increased feelings of efficacy and action responses. This is consistent with Protection Motivation Theory, which attributes the success of fear appeals to how individuals judge the magnitude of harm, the probability of event occurrence and the efficacy of coping response. More research on the role of visual imagery (both positive and negative), particularly in combination with other types risk information, is needed to better understand these effects.

Indeed, participants exposed to more complex risk information, even when a photo was present, did not have the same ethical intuitions and emotional responses as those in simple risk framings. Findings suggest that more complex mental computations require more objective and less emotionally intuitive thought processes, and, as such, the impact of affect and availability heuristics is reduced. As a result, investment decisions are more dependent on objective rationality when economic impacts are framed as a range, even when a photo is present. Although there was no difference in investment behaviour between the two impact framings, the increased mental effort required to decode risk information in range framings may reduce personal engagement with the issue, particularly among those less numerate, thus reducing motivation to act. Previous studies have linked higher levels of uncertainty in climate communications with a reduced willingness to act, the extent of which is mediated by feelings of efficacy (Morton et al., 2011). Other research has shown that behavioural intentions and concern for victims depends greatly on the numeracy of individuals (Hart, 2013). One should acknowledge that scientific and numeric literacy varies widely across policymakers, but decisions often require multi-level and inter-departmental cooperation. Thus, the complexity of risk information may have different effects on different actors, and may greatly influence the outcomes of decision-making.

The effect of experience is another convincing motivator. Findings show that risk acceptability decreased for those who experienced economic losses between the two periods, but stayed the same for those who did not experience loss. The effect of experience is consistent with the literature on drivers of risk perception, demonstrating that recent personal experience with climate change can indeed strongly influence how we value its risks (Akerlof et al., 2013; Kellens et al., 2011; Lawrence et al., 2014; Lujala et al., 2015; van der Linden, 2014). Interestingly, among those participants that experienced losses, the change from a description-based to an experience-based understanding of risk does not seem to evoke decision-making based on particularly strong emotional responses, levels of concern, or feelings of moral responsibility. Rather, it seems to arouse an intuitive reaction that is both salient and transient. Since there was no information change between Period 1 and Period 2, the experience of losses (objectively speaking) should not imply a change in risk acceptability between the two periods, unless this change is otherwise accompanied by emotive reactions to loss that override past decision-making, e.g. dealing with the aftermath of a flood might be emotionally taxing and could induce stress and anxiety due to cost factors (Foudi et al., 2017), thus lowering acceptability of future risks.

Results indicate that there are distinct differences between the types of cognitive and emotional reasoning governing decision-making in Period 1, when initial appraisals of risk acceptability are made, and decision-making in Period 2, when risk acceptability becomes dependent on whether or not a loss was experienced. While in the case of the former, different framings of risk may evoke more (when accompanied by imagery) or less (when information is more complex) emotional response, decision making is still contingent on different forms of (objective or practical) rationality. Once a loss has been experienced, decision-making directly after its occurrence is more reaction-based, reliant on a sense of gut reaction or instinct (heuristics that may be more error prone), to correct for past mistakes.

5.4.1. Policy recommendations

The results from this experiment teach us that photos of climate impacts can be an effective medium for provoking visceral feelings about climate change. When used in conjunction with simple numerical risk information, photos can help the public engage more deeply with climate issues, and in turn encourage them to take precautionary measures to limit future losses. Risk communications may be more effective if it promotes a moral reasoning of the issue, appealing to the emotions of policymakers and people working in industry as much as to the public. Reducing the complexity of risk information could also help to engage a wider spectrum of actors with different cognitive and analytical capabilities, particularly those whose sense of personal efficacy may be hindered by grim or overwhelming risk statistics. Finally, decision-processes leading to reactive adaptation (actions taken directly after experiencing climate impacts), should be deliberative and strive to use both cognitive and emotional reasoning, so as to reduce the potential for ineffective adaptation or maladaptation in the future.

5.4.2. Study limitations

Future research should explore how different types of photographic message motivate action, e.g. whether a photo of flooding impacts on infrastructure evokes different feelings to a photo of flooding impacts on communities? In the same vein, are photos an equally effective risk communication tool for other types of climate hazard, e.g. heat waves and drought? Risk communication research would also benefit from a deeper exploration into the impact of different types of visual instruments, i.e. the arts, video, graphics, infographics and cartography.

Factors pertaining to the mental model, such as concern and moral responsibility, were measured in a post-experiment survey, but these indicators could be measured both before and after the experiment to check for more precise framing and experience effects. Income effects were not measured in this study, but could also be an important determining factor of investment and risk decision-making.

Finally, it is not unreasonable to expect distinct differences in decision processes for individuals versus actual policymakers. Individuals are likely to make decisions that affect their own personal gains, while policymakers are often concerned with the utility of multiple actors (i.e. various organisations, departments, sectors, different societal groups, or society as a whole). Of course, policymakers might also be concerned about personal gains, but this type of decision-making would undoubtedly require the consideration of more moral or ethical dimensions as choices would affect entities outside of oneself. Moral decision-making is also likely to play a greater role for policymakers in the public eye, who must consider their level of accountability when it comes to taking decisions with potentially grave consequences. While we would expect participants to be motivated by individual gains (insomuch as their payoffs are determined by the hypothetical choices they make during the experiment), asking them to assume the role of a policymaker might also activate a greater sense of moral duty and responsibility when deciding between actions and enable a better study of practical versus objective rationality within decision-making. An interesting next step would be to test how actual policymakers react to the presentation of information, since their responses may differ from those of the general population. Testing the influence of these framing effects on individuals with different numerical and analytical capabilities could also provide important insight into how different actors might respond to climate risks.

5.5. Conclusions

This study contributes to the literature on climate change risk communication by providing experimental data on the effect of different framings and experience on responses to climate change risks, and more specifically to risk of flooding. Real decisions based on costs, risks and probabilities of different options were explored. Findings suggest that visual communications that show a photo of potential climate impacts alongside simple numerical expressions of risk can help decision-makers make deliberate choices based on both cognitive and emotional reasoning. Results show that more complex presentations of risk may lessen the effect of important moral and emotional rationalisation when deciding between actions. Researchers should look further into the distinct differences in emotional reasoning based on long-lasting narratives (such as evoked under certain risk framings) and reactive response (such as evoked directly after the experience of a climate event). The latter may induce biases and heuristics that lead to less rational responses to risk. Future research should strive to explore these fundamental differences further, both empirically and based on real outcomes. Understanding how best to communicate climate change risks will become especially relevant in future years as climate risks increase and dramatic outcomes become more frequent. Risk communication research that explores basic cognitive and emotional reasoning when it comes to processing complex risk information, will undoubtedly lead to more successful risk communication strategies that enable better preparedness in light of future climate risks and impacts.

Chapter 6: The cognitive and experiential effects of flood risk framings and experience, and their influence on adaptation investment behaviour

6.1. Introduction

The prevalence of climate change has become more apparent in recent years, with growing reports of more frequent and extreme weather events affecting many regions across the globe. Despite these effects, many studies have reported public disengagement with the issue of climate change, linked to a perception of impacts as being both psychologically and temporally distant in nature (Leiserowitz, 2007; Lorenzoni et al., 2007; Nicholson-Cole, 2005). For this reason, scientists have been stressing the importance of devising effective risk communication strategies for motivating action, both from citizens and policymakers alike, to help deal with the anticipated impacts of climate change. One of the most pressing areas of climate risk research, relates to the communication and management of flood risks. In the absence of future adaptation, a 1.5°C warming is expected to dramatically worsen flooding impacts worldwide, with recent estimates suggesting an increase in human losses by 70-83%, direct flood damage by 160-240%, and a reduction in relative welfare by 0.23-0.29% (Dottori et al., 2018).

In light of this, traditional engineering-based approaches are being replaced by more integrated risk-based management techniques, which consider social aspects such as flood preparedness and response, to help deal with impacts (Kellens et al., 2013). This shift has led to a growing body of research exploring the effects of flood risk communications on aspects such as risk perceptions, behavioural responses and institutional management. Studies suggest that normative approaches to flood risk communication, which centre around transmitting objective expert assessments of so-called 'risk-statistics', have been largely ineffective at motivating the public to respond. Some argue that the dichotomy between expert assessments of risks and public understandings of risk, may be responsible for a deficit model of public (mis)understanding and engagement (Demeritt and Nobert, 2014). Indeed, it is reasonable to assume that audiences with different analytical and cognitive capabilities will interpret the richness of flood risk information, which often involves complex descriptors such as uncertainties, probabilities and impacts, in different ways, with reports of public confusion over items such as return periods (Bell and Tobin, 2007; Highfield et al., 2013) and the probabilities associated with precipitation forecasts (Gigerenzer et al., 2005). Even commonly used communication devices such as flood risk maps, which have been argued to make the global, complex and chronic hazards of climate change more local, tangible and personally relevant (Retchless, 2018), are based on design recommendations and consultations with experts (Kunz et al., 2011; Meyer et al., 2012; Van Alphen et al., 2009), despite indications that such maps may lead the public to underestimate their risk exposure or to ignore risks entirely (Burningham et al., 2008; Harvatt et al., 2011; Roth, 2009). Climate risk communicators have also recommended using issue framings that make climate impacts feel more personally relevant. As Moser (2014) asserts, personal connection and feelings of being at risk increase when a hazard feels personalised as opposed to abstract. Casting climate change as a public health issue for example, has been shown to elicit positive emotional responses, increase public engagement and understanding, and promote support for climate change mitigation and adaptation (Maibach et al., 2010; Myers et al., 2012; Petrovic et al., 2014). Other studies report an increased likelihood to engage in pro-environmental behaviours when individuals feel that climate change could affect or endanger their way of life (Semenza et al., 2011). While the evidence seems convincing, some authors stress that attempts to frame climate policy in relation to non-climate issues in a way that makes people feel personally affected may fail if the issue is not seen as being sufficiently relevant (Walker et al., 2018), and there is still insufficient evidence to support the use of personally relevant framings in flood risk communications. Nevertheless, the need for risk communication devices that move away from purely cognitive interpretations of risk, towards more experiential forms of information processing, that are more intuitive and affect-driven, so-called risk as feelings, is advocated for by authors such as Slovic (2004) and Loewenstein (2001). Supporters of formal risk analysis argue that this could lead to cognitive biases and errors in judgment that may induce irrational forms of decision-making, while others theorise that communications that help to recall past experiences and trigger affective responses are necessary for helping individuals to understand the moral impact of risks, and that this may lead to decisions based on a different form of (practical) rationality, one which uses a combination of both emotional and logical reasoning for making decisions (Roeser, 2010, 2010).

There is certainly ample evidence pointing to the influence of experiential factors on risk perceptions and behavioural responses. Many have documented that personal experience with previous flood events, for example, can increase feelings of concern and efficacy, as well as strengthening the perceived salience and response to risk communications (Burningham et al., 2008; Harvatt et al., 2011; Kellens et al., 2011; Lawrence et al., 2014; Siegrist and Gutscher, 2008, 2006; Spence et al., 2011). There are however, some conflicting results on the effects of previous flood experience on risk behaviour and responses (Soane et al., 2010; Whitmarsh, 2008). The emotions aroused when recalling past experiences may be transient rather than conducive to long-term behavioural changes, and it remains unclear how best to stimulate the effect of experience within flood risk communications. Some scholars propose the use of communications that seek to access the negative emotions associated with experiencing a flood (Miceli et al., 2008; Siegrist and Gutscher, 2008; Takao et al., 2004; Terpstra, 2011; Zaalberg et al., 2009), and many studies have demonstrated the potential for negative affect to motivate action on climate change in general (Cooper and Nisbet, 2016; Leiserowitz, 2006; Otieno et al., 2014; Smith and Leiserowitz, 2012; Spence and Pidgeon, 2010; van der Linden, 2014). Consequently, fear appeals have been employed extensively in risk communication efforts on climate change, despite indications that protection motivation may be more complex than this. Studies have shown that discrete emotions, such as feelings of worry, interest and hope, may have stronger effects on behavioural change and climate policy support than negative affect alone (Smith and Leiserowitz, 2014). Discrete emotions can also influence an individual's predisposition to take risks, and similar emotions (i.e. distress and anger) can have opposite effects, acting to either amplify or depress the impact of certain risk framings (Druckman and McDermott, 2008). Risk behaviour could also be directly affected or mediated by aspects such as feelings of personal efficacy (Brody et al., 2008; Fox-Rogers et al., 2016; Hidalgo and Pisano, 2010), trust in scientists and governments (Kellstedt et al., 2008), place attachment (Bonaiuto et al., 2016; De Dominicis et al., 2015; Mishra et al., 2010), and social norms and value systems (van der Linden, 2014).

Some have stressed that the balance of experiential factors with other important cognitive aspects necessary for processing risk information must also be considered. In line with dual process theories (Chaiken and Trope, 1999; Epstein, 1994; Kahneman and Frederick, 2002; Sloman, 1996), Marx et al. (2007) discover that experiential and analytic systems compete when processing uncertain climate information, but compared to purely statistical presentations of information, descriptions which are designed to help decision-makers recall relevant personal experience and elicit affective responses are more effective at attracting attention, heightening perceptions of risks, and influencing both individual behavioural intentions and public policy preferences in relation to climate change. The authors argue that while experience- and affective-based communications are more salient and motivating, the many abstract aspects of climate variability and change require a certain level of analytical understanding for making decisions.

As it stands, attempts to establish best-practice guidelines for flood risk communications are hindered by the lack of experimental and randomised trails necessary for testing preferences and communication formats across different audiences (Demeritt and Nobert, 2014; Spiegelhalter et al., 2011). In particular, there is weak empirical evidence on the experiential and cognitive effects of different types of flood risk framings, and their impact on behaviour (Kellens et al., 2013). Controlled experiments that examine commonly used components of flood risk communications (such as maps and impact descriptors), their effect on cognitive and experiential information processing, and ultimately on behaviour, could help in building a necessary theoretical framework for identifying and selecting design features most conducive to effective risk communication.

6.1.1. Current study

The hilly terrain, steep valleys, high precipitation levels, and densely urbanised low-lying areas of the Basque Country, make it an area extremely prone to flooding (Basque Government, 2007). With climate change, the average sea-level is expected to rise between 29 and 49 cm by the end of the 21st century, eroding beaches and increasing the risk of flooding in estuaries throughout the region (Chust et al., 2011). The economic impact of floods on infrastructures, transport and communication networks, clean-up efforts, and emergency services, is estimated to cost over €62 million annually (Gobierno Vasco, 2015). Following the establishment of the EU floods Directive (2007/60/EC), the Basque government called for an assessment of climate change induced sea-level rise and flooding in the region and produced flood risk maps to better visualise vulnerable coastal and inland flood zones. Although these maps are publicly available, there is no evidence on their effectiveness as risk communication devices and for motivating preparedness behaviour. In addition, these maps are accompanied by a wealth of (relatively complex) information related to various types of impacts (i.e. economic, environmental, social) and with respect to different return periods (T10, T100 and T500), which may be difficult for users to interpret.

Based on this, this study sets out to explore the effectiveness of flood maps and risk information provided for the Basque Country as communication devices for motivating preparedness behaviour. Different risk framings have been designed to test differences in cognitive and experiential modes of information processing, and the effect that this may have on decision-making under risk and uncertainty, based on the following research questions:

1. Does seeing a map of flood risk zones (compared to a text-only frame) induce greater experiential processing of risk information, leading to lower appraisals of risk acceptability?
2. Does framing impacts caused by a flood event as more personally relevant (persons affected) compared to more abstract framings (economic losses) induce greater experiential processing, leading to lower levels of risk acceptability?

The subsequent research hypotheses have been constructed to facilitate an answering of these questions:

H1. Seeing a map of flood risk zones will reduce the psychological distance of flooding impacts, making them seem more local and personally relevant, leading to greater perceptions of flood risks and lower appraisals of risk acceptability. Participants that only see text are expected to use primarily cognitive forms of information processing, while those who also see a map are expected to use a combination of both cognitive and experiential forms of information processing. In the case of the latter, experiential processing will lead to a better recollection of past experiences and long-lasting narratives on climate change, causing more affect-driven responses, and a moral reasoning of climate risks.

H2. Primarily cognitive forms of information processing are expected for participants who see flood impacts framed as economic losses, leading to more objective appraisals of risk acceptability. For participants that see framings of flood impacts presented as more personally relevant (number of persons affected), risk perceptions are expected to be higher, leading to appraisals of risk acceptability that are more subjective and affect-driven in nature. A concern for victims may also drive a sense of moral responsibility, which may lead to a lower acceptance of risks.

The aforementioned risk framings are expected to elicit decisions based on objective (cognitive) and practical (cognitive and emotional) forms of rationality. All framings require an analytical assessment of the same risk statistics; therefore, no framing is expected to induce decision-making based purely on emotion, which as some have suggested, may lead to cognitive bias and errors in judgement. In order to assess the difference in actions based on objective or practical forms of rationality, and actions prone to more irrational (or cognitively biased) forms of decision-making, a third research question is proposed:

3. If risk statistics remain unchanged, does 'experiencing', or similarly, 'not experiencing' a (hypothetical) flood event lead to differences in initial appraisals of risk acceptability?

H3. If the information pertaining to a risk is equivalent at two decision points, then rational choice theory dictates that preferences should stay the same between the two points irrespective of whether an event occurs or not. In reality, experiencing a flood event may evoke transient (likely negative) emotional responses (i.e. stress, anxiety, fear) that may cause one to perceive risks as more severe (or less acceptable) than once thought and to take on precautionary measures to avoid the same outcome in the future. In the same way, investing in protection and not experiencing a flood event may evoke (likely positive) emotional responses (i.e. feelings of empowerment or activeness), causing one to perceive risks as less severe (or more acceptable) than once thought, thus reducing precautionary behaviour. Thus, compared to initial risk assessments, risk acceptability is expected to reduce for participants that experience losses and increase for participants that do not experience losses.

6.2. Materials and methods

An incentivised computerised economic lab experiment was designed to answer and test the aforementioned research questions and hypotheses. The experimental approach consists of three distinct parts; i) a risk-elicitation task for testing participants' risk propensity, ii) a role-playing exercise to measure levels of risk acceptability in response to different risk framings, and iii) a post-experiment survey for assessing cognitive and experiential factors involved in the decision-making process, as well as effects pertaining to various socio-demographic factors such as gender, age and nationality.

6.2.1. Measures

Risk propensity

Risk behaviour was measured using a staircase risk-elicitation procedure established by Falk et al. (2016) (Supplemental File 1). This task consisted of asking participants to make five consecutive choices between a lottery, which stays the same for each decision, and a sure payment, which changes after each decision. After the first choice has been made, the sure payment is adjusted in each subsequent decision to be higher (when the lottery is chosen) or lower (when the sure payment is chosen), in order to arrive at the implied switching row of the individual, that is, the point at which the sure payment is preferred to the lottery. Based on this implied switching row, risk scores are estimated for each individual, ranging from 1 (very risk-averse) to 31 (very risk-taking).

Risk acceptability

Following the risk-elicitation task, participants are asked to assume the role of a policy-maker responsible for the Basque coastal town of Zarautz. Zarautz was chosen for this part of the experiment, since it is a well-known area at risk of climate impacts, with extensive media coverage of past extreme storm events and coastal flooding. A 2x2 between subject design was used to measure the effect of different visual (map vs. no map) and impact (abstract vs. personal) risk framings. Participants were randomly allocated to one of the four treatment groups and were given information related to the impacts and probabilities of a flood event. Participants were also given a budget (in experimental tokens) out of which any investment in protection and damages suffered would be deducted. Depending on the treatment group, participants saw impacts framed as either economic losses, or as the number of people that would be affected if a flood event occurred. Impacts were described to participants in real terms, based on actual figures from the Basque Government. To maintain consistency between treatments and reduce the potential for confounding effects, impacts were translated to a fixed value in experimental points, equivalent between treatments, which represented potential losses in the game. As with the impact framings, half of the participants saw a map of flood zones while the other half did not. Flood maps were simplified, such that all accompanying information was removed leaving just the image of flood zones depicting low, medium and high-risk areas[37]. Participants were then asked how much they were willing to invest in protective measures to reduce their risks (probability of experiencing impacts) in the future. A table of options was provided, consisting of 19 solutions ranging from no-protection at all (95% chance of experiencing impacts) to maximum protection (5% chance of experiencing impacts). The options were designed such that each equivalent increase in the cost of protection (option 1 costing nothing, and option 19 being the most expensive), resulted in the same

[37] The original version of the map depicts zones at risk of 10, 100 and 500-year flood events, but for simplistic purposes and to reduce the potential for confounding effects, these were shown as high, medium and low-risk areas, respectively, instead.

reduction in the likelihood of experiencing impacts (option 1 having the greatest exposure to risks, option 19 having the least exposure to risks). To simplify the concept of probabilities, and to increase the feeling of trust that the likelihood of experiencing flooding impacts was based purely on chance, probabilities of experiencing losses were explained to participants through a 20-sided die. Two sets of numbers between 1-20 were provided alongside each option on the table, one set representing a failure to the protect the town, and the other set representing the successful protection of the town. Depending on which option participants chose, the numbers corresponding to each set varied. Once participants decided on an option, a computerised die randomly generated a number between 1 and 20, which depending on the option, meant they either managed to protect or failed to protect the town from flooding. The cost of protection and damage (if any) suffered, was then deducted from their initial budget. Levels of risk acceptability were determined based on the chosen option, option 1 symbolising a very high level of risk acceptability (no motivation to be risk reducing, with no investment in protection), and option 19 representing a very low level of risk acceptability (high motivation to be risk reducing, with maximum investment in protection).

Experience

A 2-period repeated-game design was used to measure risk acceptability in response to experiencing a hypothetical flood event. Participants were asked to make an investment in protection (select an option) at two decision points, Period 1 and Period 2. All protection options, their respective costs, as well as the probabilities and costs of impacts remained the same across the two decision points. Once participants selected their option in the first period and discovered whether they managed to protect the town from flooding or not, they were asked to select an option to invest in again for the second period. Participants were instructed to assume that all previous protection had been stripped, the only difference in Period 2 being the experience they had gained from their decision in Period 1. The difference in level of risk acceptability between Period 1 and Period 2 for those who experienced losses and for those who did not experience losses between the two periods, was used to measure the effect of experience.

Experiential and cognitive reasoning

A post-experiment survey measured factors pertaining to the experiential and cognitive information processing of risk information. For a measure of analytical reasoning, participants were asked to rate how difficult they found the task. In line with dual process theories, the level of cognitive effort was assumed to be related to the level of analytical (or cognitive) reasoning. Such that, the higher the level of difficulty, the higher the cognitive effort spent, and the more objective or analytical the decision-making process. The psychological positive and negative affect scales developed by Watson et al. (1988) were then employed as a measure of participants' level of emotional reasoning. Participants were asked to rate their level of affect related to the experiment, based on a selection of 8 positive affect items (enthusiastic, interested, determined, emotional, inspired, concentrated, active, empowered) and 8 negative affect items (scared, afraid, upset, distressed, tense, nervous, guilty, irritable). Both discrete emotions, as well as grouped positive and negative affect scores, were assessed. In the same way, participants were asked to rate their level of concern about the impacts of climate change in Zarautz. The extent that participants felt a moral responsibility towards climate change was determined by asking them how much they agreed with the statement: "We have a moral duty to act on climate change for our planet, its animals, its plants and its people."

Risk perceptions, and perceptions of the psychological and temporal distance of climate change were also measured. First, by asking participants to rate the extent they thought climate change would impact "them personally", "their family", "people in their region", "people in Spain", "people in industrialised countries", "people in developing countries", "future generations", and "plant and animal species". Next, by asking participants to select when they thought climate change would impact people, i) in Spain and, ii) in other parts of the world, out of the following items: "they are being harmed now", "in 10 years", "in 25 years", "in 50 years", "in 100 years", and "never".

Two separate items were used to assess the level of importance that individuals place on climate change. The first, asked participants to rate how much they had thought about climate change before the experiment, and the second, asked participants to rate how important the issue of climate change was to them personally. Lastly, levels of self-efficacy were measured by asking participants to what extent they agreed with the following statement: "The actions I take won't make any difference to climate change." All rating scores for the aforementioned items were measured using a 7-point Likert scale.

Climate change beliefs, past experience, place attachment and socio-demographics

Beliefs about climate change were assessed by asking participants to select which of the following best described their thoughts on climate change: "I don't think climate change is happening", "I have no idea whether climate change is happening or not", "I think that climate change is happening, but it's just a natural fluctuation in Earth's temperatures", "I think that climate change is happening, and I think that humans are largely causing it". Participants were also asked whether they felt they had personally experienced the effects of extreme climate events (e.g. flooding, extreme storms, heat waves and/or drought) in the past. Feelings of place attachment were measured by asking whether, and if so how many times, participants had visited Zarautz in the last 12 months, as well as asking participants the extent to which they agreed (using a 7-point Likert scale) with the following 4 items: "Zarautz is a very special place to me", "I identify strongly with Zarautz", "I am very attached to Zarautz", and "no other place can compare to Zarautz". A final item was included which asked participants whether they thought they would invest “more”, “less”, or “the same amount”, if the exercise was focused on a region outside of the Basque Country. Finally, potential explanatory measures related to participants’ nationality, sense of Basque identity, age, and gender, were collected at the end of the post-experiment survey.

6.2.2. The sample

A computerised lab experiment was conducted at the University of the Basque Country in Bilbao, in October 2019. One-hundred-sixty students participated in the experiment, with each treatment group consisting of around 40 participants. The experiment was translated to and conducted in Spanish. The sample comprised 54% female, 45% male, and <1% non-binary individuals, with ages ranging from under 18 to over 45, with the majority of participants aged between 18 and 24 (82%). The large majority of participants were Spanish (94%), of which, 85% identified as Basque. The experiment was incentivised so participants could experience real gains and losses during the experiment, by earning experimental tokens (€1=50 tokens) during the first two tasks (the risk elicitation task and the role-playing exercise). Participants were able to earn a maximum of 150 experimental tokens (€3 equivalent) during the first task, and a maximum of 600 experimental tokens (€12 equivalent) during the second task.

6.3. Analysis and results

This section describes the results of a series of Analyses of Variance tests (Lindman, 1974) used to test the aforementioned research questions and hypotheses. Logistic regressions have also been conducted to study the strength of predictor variables. Descriptive statistics pertaining to the individual treatment groups is also provided. All statistical tests and analyses have been conducted using the statistical software package R.

6.3.1. General perceptions of climate risks and impacts

On the whole, results support findings from previous studies, which show a general perception of climate impacts as being psychologically distant in nature (Fig. 16). Perceptions of threat increase with the spatial and temporal distance of affected groups, with those judged as proximally close (oneself and family) perceived as being less severely impacted than those judged to be proximally distant (future generations and plant/animal species).

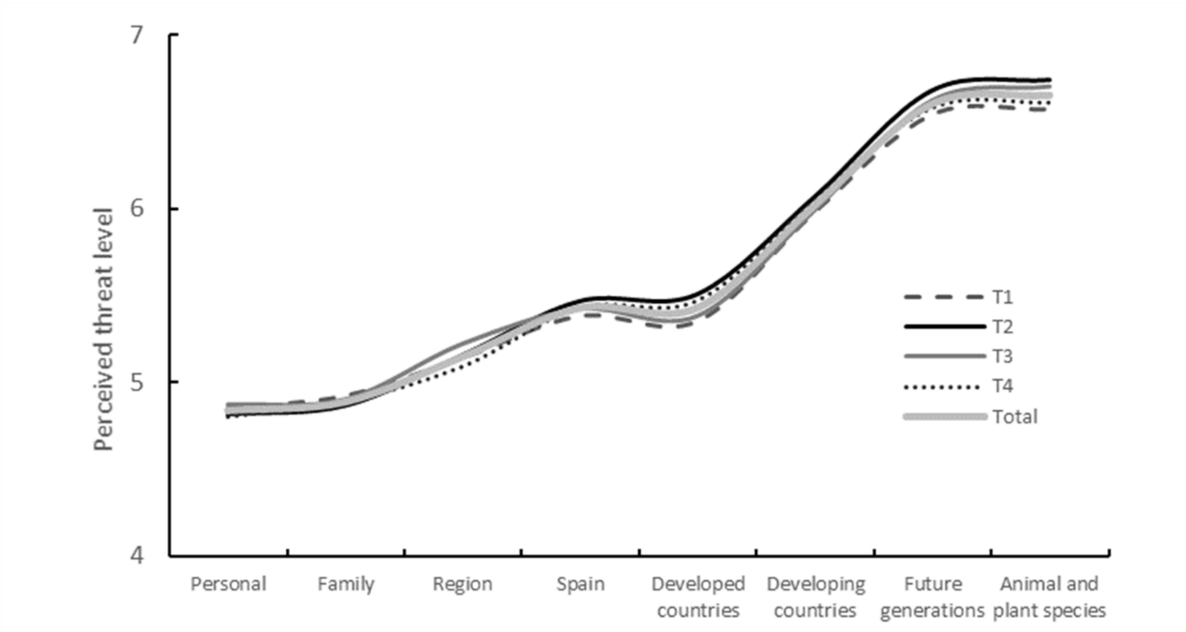


Figure 16. Perceived psychological distance of climate impacts for different treatment groups

Contrastingly, climate change was generally perceived as being temporally close, with the majority of respondents agreeing that climate impacts are already being felt across many parts of the world (Fig. 17). Yet, judgements of temporal distance were also sensitive to proximal distance, such that participants expected climate change to affect Spain later than it would the rest of the world.

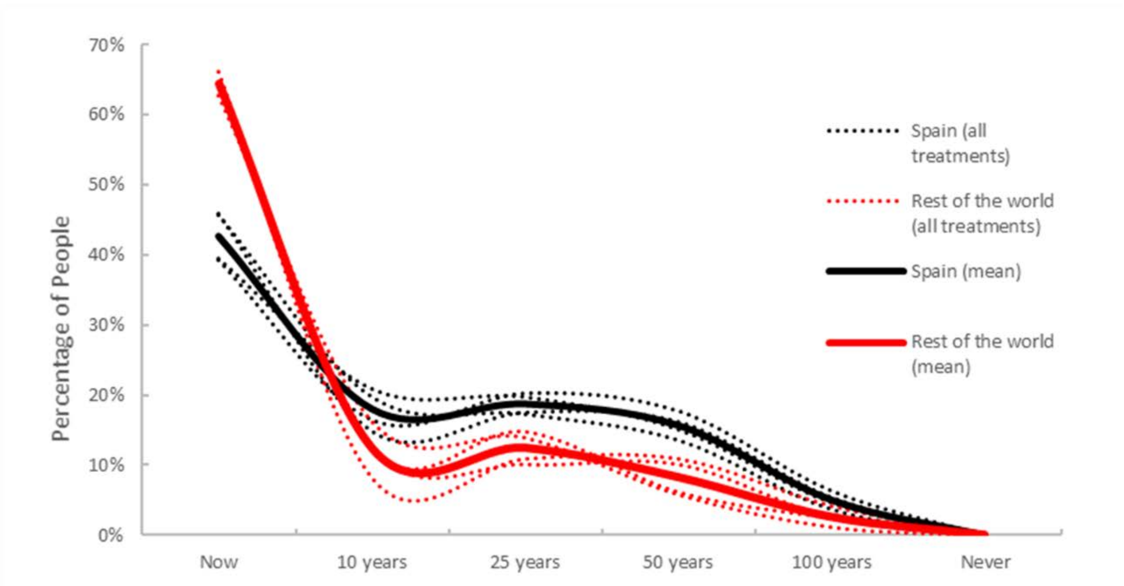


Figure 17. Perceived temporal distance of climate impacts for distant (rest of the world) and proximal (Spain) impacts

The importance that participants placed on climate change, as well risk perceptions of distant impacts, were the most significant factors driving risk perceptions of proximal impacts (see Appendix X for the full model, which explains 66% of the variance in proximal risk perceptions). Climate importance was also a main driver of perceptions of distant risks, but judgements of these risks were also affected by the expected timing of impacts (temporal distance), as well as more proximal factors, such as the perceived severity of proximal impacts and how concerned participants were about the effects of climate change in Zarautz (see Appendix XI for the full model, which explains 68% of the variability in risk perceptions of distant impacts).

6.3.2. Cognitive and experiential effects of different flood risk framings on risk acceptability

Contrary to hypothesis H1, results indicate that participants who were exposed to a map of flood zones had higher levels of risk acceptability (invested less in protection), compared to those in text-only treatment groups, $F(1,158)=4.158$, p-value=0.0431. Those that saw a map also reported lower ratings of self-efficacy, $F(1,158)=6.683$, p-value=0.011, and lower levels of affect, $F(1,158)=6.01$, p-value=0.0153, related to their extent of interest, $F(1,158)=4.168$, p-value=0.0429, activeness, $F(1,158)=4.15$, p-value=0.0433, and concentration, $F(1,158)=4.005$, p-value=0.0471. Those in map treatment groups also attributed lower levels of importance to climate change in general, compared to those that only saw text, $F(1,158)=4.858$, p-value=0.029. Lower feelings of place attachment were reported for map treatment groups, $F(1,142)=6.178$, p-value=0.0141, with 74 percent of participants having visited Zarautz, compared to 81 percent in text-only treatments.

No significant difference in levels of risk acceptability were found between participants that saw impacts framed as economic losses and those that saw impacts framed as more personally relevant, $F(1,158)=0.105$, p-value=0.747. Similarly, no significant differences in (personal and impersonal) perceptions of risk, $F(1,158)=0.018$, p-value=0.894, affect, $F(1,158)=0.197$, p-value=0.658, sense of moral responsibility, $F(1,158)=0.064$, p-value=0.8, or concern, $F(1,158)=0.818$, p-value=0.367, were detected between the two impact framings. A summary of descriptive statistics (mean and standard deviations) for the four treatment groups are shown in Table 18.

Table 18. Summary statistics for visual and impact framings

	Visual framing:		*Impact/loss framing:*	
	Map	Text-only	Economic	Persons affected
Risk acceptability				
Investment P1	89.12 (26.97)	98.05 (28.40)	93.97 (27.22)	92.54 (28.73)
Cognitive effort				
Task difficulty	2.36 (1.46)	2.068 (1.24)	2.114 (1.30)	2.333 (1.43)
Concern & moral responsibility				
Concern	5.15 (1.66)	5.41 (1.36)	5.38 (1.29)	5.16 (1.74)
Moral responsibility	6.41 (0.95)	6.55 (0.88)	6.49 (0.88)	6.48 (0.96)
Affect & self-efficacy				
Positive affect	35.21 (9.49)	37.85 (9.76)	35.70 (9.82)	37.15 (9.54)
Negative affect	23.88 (10.73)	22.73 (9.12)	22.92 (10.11)	23.77 (9.95)
Self-efficacy	5.40 (1.74)	6.04 (1.35)	5.57 (1.69)	5.82 (1.51)
Climate importance	5.55 (1.38)	5.97 (1.01)	5.73 (1.03)	5.75 (1.41)

Note: Values represent the mean with standard deviations in brackets

The results of four regression models showing the main drivers of risk acceptability for the four treatment groups are shown in Table 19. Consistent with hypothesis H1, findings indicate that appraisals of risk acceptability for participants in map framings are driven by primarily experiential forms of information processing as well as a sense of moral responsibility, with model 1 explaining 39% of the variance in levels of risk acceptability. As hypothesised, factors explaining risk acceptability for text-only treatments are largely cognitive in nature, with risk propensity and concentration being primary drivers (model 2).

Similarly, and consistent with hypothesis H2, appraisals of risk acceptability for participants in impact groups framed as more personally relevant, are driven largely by experiential factors, such as affect and feelings of self-efficacy. Discrete emotions that are similar in nature, such as interest and enthusiasm, seem to have opposite effects, acting to amplify and depress framing effects, respectively. The model, which explains 44% of the variance in levels of risk acceptability, also highlights the use of other types of experiential processes, such as participants' sense of self-efficacy and previous experience with climate change, for making decisions (model 4). As with text-only risk framings, decisions based on impacts framed as economic losses were characterised by predominantly cognitive forms of information processing, with risk propensity and concentration identified as main predictors of risk acceptability (model 3). The models do well to explain the effects for treatment groups that are largely experiential in nature (models 1 and 4) but are less suited for risk framings that trigger primarily cognitive forms of decision-making, with models 2 and 3 explaining only 27% and 20% of the variance in risk acceptability, respectively. The inclusion of further cognitive variables, such as levels of scientific and numerical literacy, knowledge, and education, may help to better explain framing effects for these treatment groups.

6.3.3. The effect of experience on risk acceptability

A paired t-test was used to test the effects of experience on levels of risk acceptability. No significant difference in levels of risk acceptability between period 1 and period 2 was found for participants who experienced losses (p-value=0.3039). Consistent with hypothesis H3, participants who did not experience losses however, had higher levels of risk acceptability (p-value=0.0002) in period 2 (mean investment in protection=92.65, sd=29.06) compared to period 1 (mean investment in protection=101.3, sd=25.32). Participants who experienced losses had greater ratings of negative affect, in particular, they reported feeling more irritated, F(1,158)=4.661, p-value=0.0324, and more guilty, F(1,158)=6.549, p-value=0.0114, than those that did not experience losses. In comparison, those that did not experience losses had much greater levels of positive affect on the whole, F(1,158)=16.31, p-value=8.37e05. In particular, they felt more interested, F(1,158)=10.71, p-value=0.00131, more emotional, F(1,158)=8.937, p-value=0.00324, more empowered, F(1,158)=9.658, p-value=0.00224, more inspired, F(1,158)=6.554, p-value=6.554, more active, F(1,158)=7.591, p-value=0.00656, and more concentrated, F(1,158)=12.37, p-value=0.000571, than those who experienced losses.

Table 19. Regression analysis of relevant drivers of risk acceptability in visual and impact framings

	Visual framing:		*Impact/loss framing:*	
	Map (1)	Text-only (2)	Economic (3)	Personally relevant (4)
Risk				
Risk propensity		-1.18** (0.53)	-1.52*** (0.53)	
Moral responsibility				
Moral responsibility	8.41*** (2.52)			11.83*** (3.57)
Affect				
Tense	6.63*** (1.73)	-3.77** (1.76)		
Emotional	7.37*** (2.47)	-6.61** (2.67)		
Enthusiastic	-6.66*** (2.40)			-6.55** (2.49)
Nervous	-4.49*** (1.68)			
Inspired	-3.84** (1.59)			
Concentrated	5.40*** (1.57)	7.42*** (2.23)	5.28*** (1.89)	
Scared				5.40** (2.24)
Active				4.14** (1.96)
Distressed				-9.40*** (2.28)
Interested		6.18** (2.51)		9.67*** (2.41)
Efficacy & experience				
Self-efficacy				-5.25** (2.10)
Previous experience				17.24*** (5.82)
Socio-demographics				
Gender		17.98*** (6.19)		14.70** (6.39)
Constant	12.23 (17.78)	72.20***(14.60)	91.87***(14.68)	1.36 (24.68)
Observations	86	73	79	70
R^2	0.44	0.33	0.22	0.51
Adjusted R^2	0.39	0.27	0.20	0.44
Residual Std. Error	21.08 (df=78)	24.28 (df=66)	24.28 (df=76)	22.23 (df=60)
F Statistic	8.73*** (df=7; 78)	5.39*** (df=6; 66)	10.56*** (df=2; 76)	22.23*** (df=9; 60)
Note:				*p<0.1;**p<0.05;***p<0.01

It is important to note that both participants who experienced losses and those who did not experience losses invested above the medium Period 1 investment value of 72 experimental tokens (option 10, with a 50% chance of experiencing losses). However, those who experienced losses invested significantly less (mean=80.52) compared to those that did not experience losses (mean=101.3), F(1,158)=24.12, p-value=2.24e-06. Contrastingly, there was no significant difference in Period 2 investment rates between the two groups, F(1,158)=3.027, p-value=0.0839.

A regression analysis explored the cognitive and experiential effects of experience on levels of risk acceptability (Table 20). The results show that on the whole, cognitive factors explain around 45% of the variance in risk acceptability levels for period 2 (model 2). Including experiential factors improves the predictive power of the model in relation to those that experienced losses, with both cognitive and experiential factors helping to explain 58% of the variance in appraisals of risk acceptability for period 2 (model 3). In contrast, those that did not experience losses between the two periods employed primarily cognitive forms of information processing for determining levels of acceptable risk for period 2. The model, which explains 47% of the variance, shows investment behaviour in period 1 as the only significant predictor of risk acceptability in period 2 for those that did not experience losses (model 4).

6.3.4. Gender effects

Findings indicate no difference in risk propensity between women and men, F(1,157)=0.141, p-value=0.708, but women on the whole had higher perceptions of risk, F(1,157)=18.69, p-value=2.72e-05, and lower levels of risk acceptability (invested more in protection) compared to men, F(1,157)=6.621, p-value=0.011. In addition, women reported having higher levels of concern about the impacts of climate change in Zarautz, F(1,157)=8.863, p-value=0.00337, felt a greater sense of moral responsibility towards climate change, F(1,157)=11.51, p-value=0.000876, attributed greater importance to the issue of climate change in general, F(1,157)=14.12, p-value=.000242, felt more emotional, F(1,157)=4.932, p-value=0.0278, and perceived climate change as being more psychologically, F(1,157)=19.86, p-value=1.58e-05, and temporally close, F(1,157)=14.28, p-value=0.00022, compared to men. As shown in table 19, gender effects were evident in risk framings that triggered both experiential and cognitive forms of information processing, with women exposed to these treatments investing more in protection compared to men.

Table 20: Regression analysis of factors affecting risk acceptability with and without the experience of losses

	Dependent variable:			
	Experience (loss=1, no loss=0) (1)	Investment P2 (2)	Investment P2 (with experience) (3)	Investment P2 (without experience) (4)
Risk behaviour				
Investment P1	-0.01*** (0.001)	0.80*** (0.07)	0.72*** (0.12)	0.82*** (0.09)
Risk propensity		0.42 (0.35)	-0.64 (0.63)	0.62 (0.38)
Cognitive effort				
Task difficulty		2.73** (1.34)	9.63*** (2.36)	0.49 (1.62)
Experience				
Experience (loss=1, no loss =0)		7.93** (4.04)		
Past experience			14.99*** (6.00)	
Affect				
Interested			5.61** (2.56)	
Tense			-5.74*** (2.06)	
Determined			-6.43*** (1.95)	
Temporal distance				
Proximal impacts			9.61** (3.13)	
Distant impacts			-9.41*** (3.34)	
Constant	0.98*** (0.13)	-1.85 (11.45)	21.14 (20.23)	-2.11 (13.74)
Observations	160	160	62	98
R2	0.13	0.46	0.65	0.48
Adjusted R2	0.13	0.45	0.58	0.47
Residual Std. Error	0.46 (df=158)	22.86 (df=155)	21.30 (df=52)	21.24 (df=94)
F Statistic	24.13*** (df=1;158)	33.60*** (df=4;155)	10.51*** (df=9;52)	29.20*** (df=3;94)
Note:				*p<0.1;**p<0.05;***p<0.01

6.4. Discussion

6.4.1. Climate change beliefs and perceptions

As evidenced by previous studies (Gifford, 2011; Gifford et al., 2009; Schultz et al., 2014; Spence et al., 2012; Uzzell, 2000), findings suggest that people have a general perception of climate change as being a psychologically distant issue, viewing proximal climate impacts as less severe than distant impacts. Scientists have attributed this to a spatial optimism bias, linked to positive feelings about one's self and community, which causes people to view distant conditions as less attractive than those closer to home (Kunda, 1990). In line with Schultz et al. (2014), greater spatial optimism was found to be associated with greater levels of engagement and concern about climate change, which may be due to self- and place-protective reasoning causing one to shift concern from hazards perceived as closer or more personally threatening, to more distant ones. Although past research indicates a discounting of climate impacts, such that people expect impacts to occur in the distant, rather than in the near future (Leiserowitz, 2007; Lorenzoni et al., 2007; Nicholson-Cole, 2005), results show that climate change was generally perceived as being temporally close, albeit still expected to affect those further away before affecting those proximally close. The more frequent reporting of climate change related weather events across news and media outlets in recent years, as well as more widespread coverage of major and youth-led climate campaigns such as the Fridays for Future school strikes and global climate strikes spearheaded by Swedish climate activist Greta Thunberg, will undoubtedly have contributed to an increasing knowledge and public awareness of climate change, particularly among younger generations, likely lessening the perceived temporal distance of climate related impacts at the same time. In fact, while previous polling data has indicated relatively low levels of public agreement on the anthropogenic nature of climate change (Leiserowitz et al., 2013), over 90 percent of participants in this study believe that climate change is caused by humans, and the large majority rated it as being a highly important issue.

6.4.2. Effectiveness of flood risk framings

Findings support those of previous studies (Burningham et al., 2008; Harvatt et al., 2011; Roth, 2009), which point to the potential ineffectiveness of maps as flood risk communication devices. While the inclusion of a map in risk communications evoked decision-making based on positive and negative affect-based reasoning and a moral assessment of risks, discrete emotions similar in nature were found to compete, acting to either amplify or depress framing effects. Moreover, those exposed to flood maps were found to have lower levels of positive affect and ratings of self-efficacy, with decisions largely based on experiential, rather than cognitive forms of information processing. In general, these effects led to a higher acceptability of risks, prompting more risk-taking behaviour, and less precautionary action responses as a result. In contrast to previous assertions that maps may help to make risks more local and personally relevant (Retchless, 2018), maps were generally ineffective at helping participants to recall past experiences, and those exposed to them did not have particularly high perceptions of personal risks, nor did they have especially close temporal perceptions of impacts. Having said that, a larger proportion of respondents reported never having visited Zarautz, and on the whole lower feelings of place attachment were observed for participants in map (compared to text-only) treatment groups.

An interesting next step would be to replicate the experiment with people from or living in Zarautz to assess whether this may yield different results.

Framings impacts as more personally relevant helped participants to recall past experiences with climate change[38] and was found to evoke more experiential forms of information processing, compared to those presented with more abstract impacts. In spite of this, framing impacts in terms of people did not evoke comparatively higher perceptions of personal risks, moral responsibility, or levels of concern, and ultimately did not induce a lower acceptability of risks, or more precautionary action responses as a result. As Walker et al. (2018) suggests, this could be due to the fact that participants did not consider these impacts to be sufficiently relevant, at least not enough to warrant significant changes in action responses. As with map framings, future research should assess whether the personal relevance of these types of impact framings changes according to various levels of place attachment. Similarly, it would be interesting to test whether the extent of personal relevance in these framings relates to the actual number of people affected. Slovic (2007) finds that people are more likely to feel compassion and donate to starving children in Africa when shown a picture of one starving child compared to when the same photo is accompanied by statistical information about the millions of starving children in Africa. In the same way, risk communications that include a narrative about a person or family that has been affected by flooding in the past may increase affective reasoning as well as precautionary behaviour as a result.

It seems that finding the right balance between cognitive and affective reasoning is an important constituent of risk communications. Indeed, the risk framing that resulted in the highest average protection in investment (the text-only framing) evoked a combination of both cognitive and emotional forms of information processing for making decisions. While not statistically significant, participants in this treatment group displayed the highest levels of concern, feelings of moral responsibility, positive affect, self-efficacy, and sense of climate importance, as well as the lowest levels of negative affect compared to any other treatment group (Table 18).

6.4.3. Cognitive and experiential effects of experience

It is reasonable to assume that lower investments in protection increase the likelihood of suffering some loss or impact as a result. This is consistent with our findings, which show that those that experienced losses between the two decisions points had lower initial investments in protection than those that did not experience losses. Results support the hypothesis (H3) that experiencing losses evokes greater levels

[38] ANOVA tests confirmed that were was no significant difference in the number of people who reported having previous experience with climate change between any of the four treatment groups. Results for map vs. text-only framings, and personal vs. economic impact framings, were: $F(1,158)=0.879$, p-value=0.35 and $F(1,158)=0.284$, p-value=595, respectively.

of negative affect, while not experiencing losses evokes greater levels of positive affect. Decisions made after the experience of losses were driven by both cognitive factors, related to participants' level of cognitive effort and initial appraisals of risk acceptability, and experiential factors, related to temporal perceptions of proximal and distant risks, specific discrete (positive and negative) emotions, and a recollection of past experiences with climate change. Not experiencing losses on the other hand, led to decisions based on primarily cognitive forms of information processing, in particular, participants' initial appraisals of risk acceptability. For this reason, one might expect a form of objective rationality, resulting in more or less equivalent appraisals of risk acceptability between decision points. Risk acceptability however, was found to increase (that is, investments in protection decreased), for those who did not experience losses. This may be due to the higher ratings of positive affect observed in this group, i.e. feelings of empowerment, activeness, and concentration, which may bestow upon individuals an increased sense of security relative to how they felt when assessing risks for the first time. Interestingly, participants that did experience losses had more or less equivalent appraisals of risks between rounds. This could relate to the generally high levels of initial investment in protection, combined with more risk-taking behaviour, which prevents individuals from investing greater amounts in protection. In both cases, individuals could be regulating decision-making with the intention of optimising future investments. As shown in Figure 18, if one perceives their initial investment to be risk-averse (A), then their second decision is likely to be similarly risk-averse if they experience losses (C), but more risk-taking if they do not experience losses (E). In the same way, if one perceives their initial investment to be risk-taking (B), then their second decision is likely to be similarly risk-taking if they do not experience losses (D), but more risk- averse if they do experience losses (E).

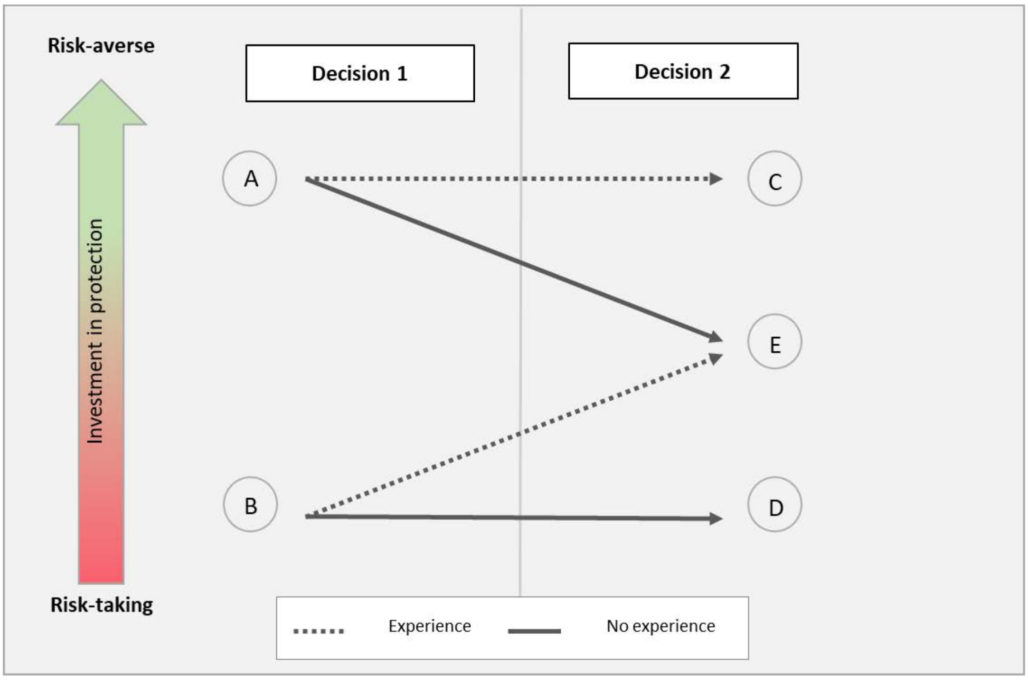


Figure 18. Potential changes in initial appraisals of risk acceptability for risk-averse and risk-taking individuals with (A-C, B-E) and without (A-E, B-D) the experience of losses between decision points

Thus, in the case of this experiment, those that experienced losses were generally risk-averse in in their first decision, and therefore continued to be risk-averse in their second decision (they moved from A to C). Those that did not experience losses were also generally risk-averse in their first decision, but the resultant positive outcome leads them to be more risk-taking in their second decision (they moved from A to E).

6.4.4. Study limitations

While the experiment reveals several noticeable effects of different flood risk framings and experience on risk behaviour, there are some limitations that should be highlighted, as well as areas to be considered for future research. Firstly, the effect of flood risk framings (particularly of map and personally relevant impact framings) may be affected by how attached individuals feel to the area under consideration (Scannell and Gifford, 2013). Re-testing the experiment with a sample of the population from Zarautz for example, would help to identify the extent to which place attachment may influence the effect of different message framings. Furthermore, the predictive power of the psychological models employed in this study would likely be improved by the inclusion of further cognitive variables, such as previous knowledge on climate change (or floods specifically) and the scientific and numerical literacy of individuals, which may impact appraisals of acceptable risks and precautionary behaviour. Future research should also explore the effect of experience across different timescales (i.e. through a measure of posttest and delayed posttest responses), to assess whether experiential effects are transient or conducive to long-term behavioural changes. Although conducting the experiment on students allows for better control of certain factors, results are reflective of a homogeneous sample (i.e. of similar ages and education levels), and it is unclear to what extent effects are synonymous with actual policy-makers. Conducting the experiment on policy-makers is not without its own challenges, and also raises questions as to which policy-makers would be suitable for this type of testing, especially given the numerous actors involved in the decision-making process across varying levels of governance and with different capabilities and responsibilities. Repeating the experiment with a representative sample of the general population may help to address some of these issues and provide insight into more widespread sociodemographic effects. Finally, much of the previous literature on climate change risk communication draws a relationship between items such as risk perceptions, concern, fear or worry and hypothetical behavioural or action responses (Cooper and Nisbet, 2016; Graham and Abrahamse, 2017; Hartmann et al., 2014; Mossler et al., 2017; Newman et al., 2012; Stevenson et al., 2014; Wiest et al., 2015). However, results of this study demonstrate that neither risk perceptions nor concern among participants were strong predictors of investment in protection. Future research should acknowledge the distinct differences between hypothetical and actual behaviour, since the former may not always be indicative of the latter.

6.5. Conclusions

This study demonstrates how diverse flood risk framings and experience with flood events can induce differences in the cognitive and experiential processing of risk information, which can ultimately impact the risk and precautionary behaviour of individuals. Flood risk maps and personally relevant impact framings were conducive to more experiential forms of decision-making, while decisions based on text-only and abstract impact framings were more cognitive in nature. While exposure to maps evoked more affect-driven responses, they were associated with lower ratings of positive affect and self-efficacy, and resulted in higher acceptability of risks and lower investments in protection. Thus, maps were generally found to be an ineffective feature of risk communications in this study, but their effectiveness may depend on the extent of which place attachment mediates the personal relevance of risk framings. Impact framings that were more personally relevant were effective at inducing a recollection of past experiences with climate change, and stimulated decision-making based on both cognitive and experiential forms of information processing. As with flood risk maps, place attachment may influence judgments of personal relevance, which in turn may act to mediate the effectiveness of personally relevant impact framings. Individuals who experienced losses from a hypothetical flood event had greater ratings of negative affect, and made decisions that were more affect-driven in nature. In contrast, individuals who did not experience losses had greater ratings of positive affect, and made subsequent decisions based on primarily cognitive factors. Investments in protection reduced for those who did not experience losses, and remained the same for those who did experience losses. Results suggest that changes in risk acceptability between decision points may be dependent on both the experience (or lack thereof) of losses, as well as the extent to which individuals were risk-averse or risk-taking in previous investment decisions.

Appendices

Appendix I. Key methodological steps considered for the systemic review of economic assessments on adaptation

Specific steps taken	Description
Research question/aim	
Set the explicit aim and objectives for the review	The objective of the review is to assess the current stake of knowledge as well as any prominent differences between studies related to how they value adaptation (i.e. what do they include? What do they exclude? How do they treat complex dimensions such as discounting, non-market values and the uncertainties of impacts and future scenarios?). In order to gain a holistic understanding of these dimensions, the review explored assessments based on diverse regions, and that covered various temporal and spatial scales.
Clear description of theoretical or conceptual approach used to guide the review	To ease the standardisation of data and information collected, as well as to facilitate the comparison across studies, a primary valuation approach was selected for assessment. Cost-benefit analysis was chosen due to its popularity as a decision-support tool across diverse subject areas, and its frequent use in adaptation contexts.
Data source and document selection	
Justification and description of literature source	In order to ensure consistency in the types and quality of assessments, the review was specifically based on peer-reviewed papers derived from reputable academic search engines, i.e. Web of Science and Google Scholar. Papers were also filtered according to language (non-English papers were excluded) and date of publication (to prioritise more recent assessments)
Articulation of search terms and/or detailed description of search process	Due to the diversity of adaptation (involving different types, scales, actors etc.), search criteria were kept as broad as possible. Search terms were defined based on economic approach ("economic valuation" OR "cost benefit analy*" OR "cost-benefit ratio*") and by adaptation to a specific type of hazard ("adapt* AND "drought" OR "flood" OR "sea level rise" OR "coastal" OR "heat" OR "heat wave*")
Description of criteria for inclusion and exclusion	Inclusion criteria were loosely defined so as not to exclude key literature sources. Exclusion criteria based on key components of cost-benefit analysis (i.e. whether assessments consider both costs and benefits, timescales and discount rates) were established.
Analyses and presentation of results	
Description of methods for analysis	A database was constructed to collect and compare relevant qualitative and quantitative criteria pertaining to each study. Standardisation techniques were used to homogenise information and to facilitate comparison between studies (i.e. converting quantitative elements into common metrics and using generic terms for grouping qualitative elements). Descriptive statistical analysis was then used to identify any emerging patterns and trends in the literature.

Appendix II. Key methodological steps considered for testing the widespread application of the EP

Specific steps taken	Description
Research question/aim	
Explicit aim and objectives	The aim of this study is to demonstrate the feasibility of the EP for promoting the protection of natural lands across diverse regions through site-specific discount rates. Europe was selected as an appropriate illustrative case-study on the basis that it satisfies the theoretical assumptions of the EP, permits a comparison of estimated discount rates across diverse natural land types, and since land-use decisions are likely to follow similar administrative processes across regions.
Clear description of theoretical or conceptual approach used	In order to test the application of the EP across European regions, data collection was focused on deriving values on natural land sites and adjacent sites zoned for development. Studies that value natural land sites were expected to employ diverse valuation approaches and differ according to which value-dimensions they considered. To maintain some order of consistency in the data pertaining to natural land values, studies were filtered according to those that consider at least one value dimension of the Total Economic Value (TEV) of natural sites. Thus, studies were filtered according to those that measured direct or indirect use values, option values, existence values, and/or bequest values of natural sites across Europe.
Data source and document selection	
Justification and description of literature source	For the collection of natural land values, a keyword search was performed using the academic search engines Web of Science and Google Scholar to filter studies that measured total or specific value components of TEV. Both studies from the academic and grey literature were considered to allow for a more widespread estimation of discount rates across regions. Studies were further filtered according to language (non-English papers were excluded) and date of publication (studies between 1990 and 2015 were considered due to the large volume of research conducted in earlier years). For the collection of data on adjacent lands zoned for development, official sources of public information on land prices were searched (i.e. departments dealing with land-use planning and statistical offices). In cases where official sources of information on land prices was unavailable, reports on real-estate markets were used instead.
Articulation of search terms and/or detailed description of search process	An initial keyword search was performed in order to filter studies that considered at least one value dimension of the TEV of natural sites. Search terms were based on economic approach (i.e. "Total Economic Value*" OR "TEV" OR "direct use value*" OR "indirect use value*" OR "option value*" OR "existence value*" OR "besquest value*") and the location of study sites. To allow for a more extensive literature search, a snowball approach was also employed to identify any potentially relevant studies based on the references cited within assessments. The search process for adjacent development lands followed a more *ad hoc* search approach. This involved determining the location and environmental characteristics of each of the natural land sites, then on a case-by-case basis,

	searching official sources of information and real-estate market reports, for suitable development land prices in neighbouring areas.
Description of criteria for inclusion and exclusion	Inclusion and exclusion criteria were loosely defined to permit a widespread application of the EP based on diverse sites across regions. Generally speaking, data on natural sites were filtered according to study location, date of publication, consideration of monetary values, and data on neighbouring development sites were filtered according to those with loose similarities in geographical and environmental characteristics.
Analyses and presentation of results	
Description of methods for analysis	A database was constructed to organise the qualitative and quantitative information pertaining to each natural site and neighbouring development site. Standardisation techniques were used to homogenise information and to facilitate comparison between studies (i.e. all monetary values were converted into common prices and were divided by site area to give values in common units per hectare). Based on the specified EP equation which equates natural and development land values (Equation 3, Chapter 3), site-specific discount rates were calculated for each study site. Descriptive statistical analysis was then used to illustrate the application of the EP across regions, and land types.

Appendix III. Key methodological steps considered for testing the effects of employment, equity and risk aversion in CBA

Specific steps taken	**Description**
Research question/aim	
Explicit aim and objectives	The aim of this study is to explore extensions of CBA that account for employment effects, equity and risk, and how they can be used to improve public decision-making related to adaptation. The first objective is to explore cost-benefit manuals and propose three existing approaches for dealing with employment, equity and risk. The second objective is to demonstrate their usefulness through a case study of an existing adaptation project.
Description of methodological approaches	Four cost-benefit analyses are conducted to assess differences in efficiency outcomes with and without the consideration of employment, equity and risk. A base CBA scenario is used that considers a simplistic assumption of costs (in terms of direct investment costs) and benefits (in terms of avoided damages from climate change). The three remaining scenarios are used to demonstrate how the partial or full consideration of employment, equity and risk factors compares with the base scenario. Shadow wages, distributional weights and risk aversion factors are used as extensions of CBA for measuring the effects of employment, equity and risk, respectively.
Data source and document selection	
Justification and description of data	An adaptation project in Bilbao (Basque Country, Spain) was chosen to test the four CBA scenarios. The city of Bilbao faces a high risk of flooding, and various adaptation measures have already been implemented to reduce risks. CBA is used to assess a hard structural solution proposed to further reduce flood risks in a relatively central part of the city. This case-study was chosen based on the availability and sufficiency of information needed for the various CBA scenarios. Costs are provided by the management commission of the project, and previous studies have estimated benefits based on different scenarios of climate change and flood events occurring.
Analyses and presentation of results	
Description of methods for analysis	Four cost-benefit analyses were conducted. The first considered a simplistic assessment of direct investment costs, and avoided damages from climate change. In the second CBA, an extension is added to the base case to consider employment effects. In the third, both employment and equity factors are considered, and the fourth considers all three extensions of employment, equity, and risk factors. All CBAs considered a time horizon between 2014 and 2080, an RCP4.5 climate scenario, a discount rate of 3.5%, and economic growth rates for the Basque Country of 2.5% between 2018-2030, 2.01% between 2031-2050 and 1.05% between 2051-2080. Avoided damages are calculated based on the probability of a 100-year flood event occurring in any given year. A sensitivity analysis is also conducted to test the variability of the benefit-cost ratio with changes in discount rates, elasticities and risk parameters.

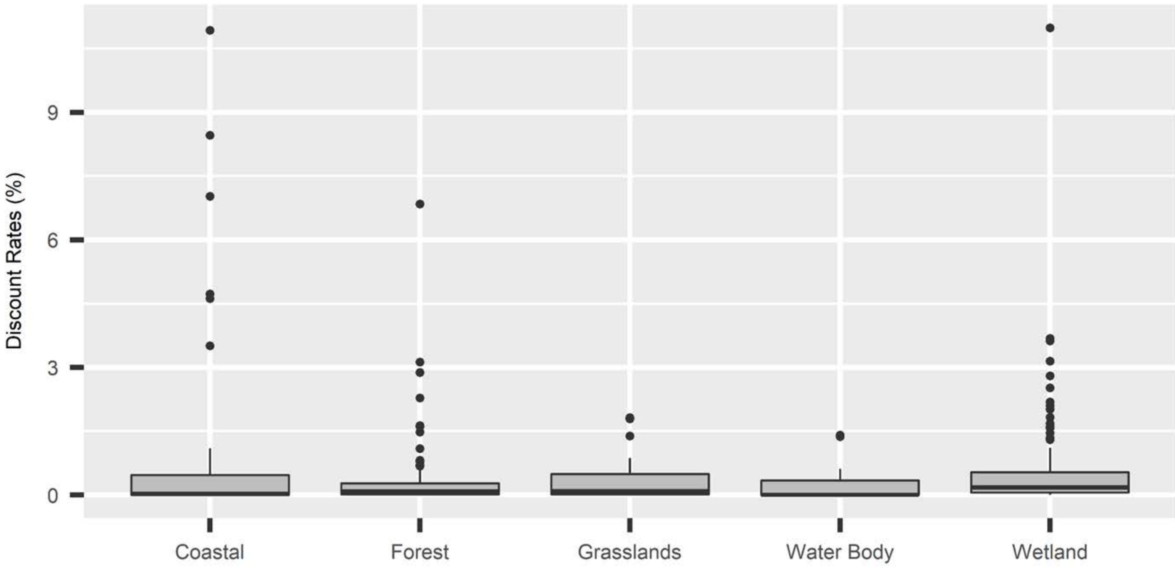
Appendix IV. Key methodological steps considered in experimental design for testing the cognitive and experiential effects of risk framings and experience and their influence on adaptation investment behaviour

Specific steps taken	**Description**
Research question/aim	
Explicit aim and objectives	The aim the experiments conducted in Chapters 4 and 5 are to study the effect of risk framings on forms of experiential and cognitive information processing of risk information, and the influence that this may have on investment behaviour related to adaptation. In order to focus the experiments and to make it relevant for people in the Basque region, flood risk in the neighbouring region of Zarautz was chosen as the focus. The experimental design was based on an assessment of risk communication devices and drivers of behaviour specific to flooding.
Description of methodological approaches	Risk preferences were measured using the well-established risk elicitation task presented in Falk et al. (2016). The experimental design used a 2x2 between subject-factorial design for measuring acceptable risk and investment behaviour related to adaptation, and a 2-period repeated game design for measuring the effect of experience. A post-experiment survey was employed for measuring the cognitive and experiential effects of different risk framings and experience.
Sample selection	
Justification and description of the sample	Experiment 1 was based on a sample of 161 participants representative of the general population in Bilbao, while experiment 2 was based on 160 student participants. The choice of students for the second experiment was mainly based on time and resource constraints, but also permitted us to control for key demographic factors such as age, knowledge, and income. Both experiments were incentivised so that choices were based on real gains and losses.
Analyses and presentation of results	
Description of methods for analysis	A combination of statistical techniques was used to measure key effects in both experiments. Primary methods included Analysis of Variance (ANOVA), logistic regression analysis, and paired t-tests, for measuring between-subject and within-subject effects.

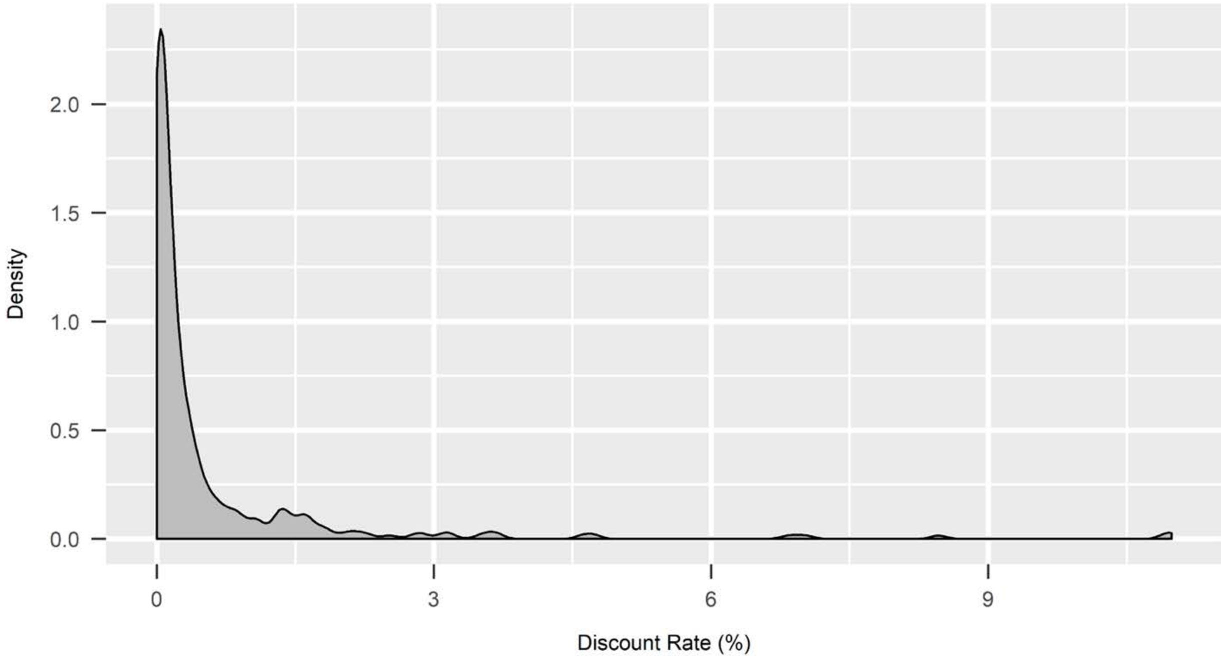
Appendix V. Description of market prices for general development, residential, industrial, office and commercial lands

Country	Price of development land (EUR, 2016)	Type	Source(s)
Belgium	943,893-1,473,394	General development (building land)	Statistics Belgium (2015)
Finland	320,000-1,675,000	Residential, industrial, commercial	National Land Survey of Finland (2016)
Germany	1,135,084	General development	Statistisches Bundesamt (2015)
Greece	1,160,503-26,111,326	Commercial, industrial, residential	NAI (2011)
Italy	99,907-1,651,263	Commercial, industrial	Average of advertised plots for sale on real estate sites in the region
Netherlands	1,018,605-239,372,093	Commercial, industrial, commercial, general development	NAI (2011)
Poland	340,278-1,020,835	Residential, industrial, commercial, general development	Central Statistical Office (2016)
Spain	894,112-2,366,317	General development, industrial	Ministerio de Fomento (2014)
Sweden	4,257,956	Residential	NAI (2011)
Turkey	3,142,829	Industrial	Colliers International (2016)
UK	991,991-4,668,192	Residential, industrial	Valuation Office Agency (2011)

Appendix VI. Box plot showing estimated discount rates by habitat type



Appendix VII. Density curve showing frequency of discount rates observed



Appendix VIII: Sensitivity analysis of EP to various elasticities

Based on a comprehensive literature search, estimates for the income elasticity of WTP were often found to be less than unity, and commonly ranged between 0.3 and 0.7 (Pearce, 2003). However this range is challenged by McFadden & Leonard (1993) and McFadden (1994), based on their assertion that an income elasticity of WTP that is less than unity does not accord with economic intuition, based on the plausibility that preservation would be a "luxury" good that for poor households is replaced by needs for food and shelter. Based on these arguments, elasticities of 0.3, 0.7, 1.0 and 1.2 were chosen to test how discount rates change as the income elasticity of WTP changes. On the grounds that an elasticity of 0.3 will mean that a 1% change in income will result in a 0.3% change in WTP, and conversely, that an elasticity of 1.2 will mean that the same 1% change in income will result in a 1.2% change in WTP, and so on and so forth. These results are included in the online supplemental material. In general, the EP was found to be insensitive to changes in elasticity. That is, for a 1% change in the value of the elasticity the discount rates vary between a minimum of 0.06% to a maximum of 0.43%. More closely, it is possible to see that for countries such as Finland and the UK, the higher the income elasticity of WTP the higher the discount rate resulting from the EP will be. That is, the more sensible the WTP to changes in income, the less you need to use the discount rate to adjust the values of the two plots (i.e. the higher the recommended discount rate is). However, in countries such as Spain and Greece this most frequently works in the opposite direction. This may suggest that demand for natural and well preserved land in richer countries is considered a normal good (i.e. income elasticity of demand being positive) while in countries with lower GDP that have been recently suffering a severe economic crisis may be seen as an inferior good (i.e. income elasticity of demand being negative). Answering this question is however well beyond the scope of this paper and may well represent a challenging research question worth exploring in detail.

Appendix IX. Average incomes in affected regions considering a 4.5RCP scenario and a 100-year return period

Region	Number of people affected	Average income
Abando	1797	35944
Atxuri	724	16434
Bilbao la vieja	1560	15108
Bolueta	33	14943
Casco Viejo	6681	24509
Castaños	4370	29160
Ibarrekolanda	0	21113
Indautxu	1	35702
Iturralde	0	19404
La Peña	866	15117
La Ribera	1121	17334
Olabeaga	168	16783
San Francisco	414	13637
San Ignacio	863	18853
San Pedro de Duesto	2237	23759
Solokoetxe	267	18304
Zorrotza	320	15431
Total	**21422**	**21245**

Appendix X. Regression analysis of factors affecting perceptions of proximal impacts (personal and familial impacts)

	Dependent variable: perceptions of personal risks			
	Proximal (1)	**Proximal + Beliefs (2)**	**Proximal + Beliefs + Distant (3)**	**Full model incl. socio-demographics (4)**
Cognitive effort	0.19**	0.13*	0.04	0.02
	(0.08)	(0.07)	(0.05)	(0.06)
Concern	0.35***	0.09	-0.04	-0.04
	(0.07)	(0.08)	(0.06)	(0.06)
Visited	-0.46*	-0.34	-0.03	-0.12
	(0.27)	(0.25)	(0.19)	(0.19)
Temporal distance (*Spain*)	-0.28***	-0.19**	-0.18**	-0.16*
	(0.09)	(0.08)	(0.09)	(0.09)
Moral responsibility		0.12	0.01	-0.0003
		(0.13)	(0.10)	(0.10)
Climate importance		0.52***	0.16*	0.17**
		(0.10)	(0.08)	(0.08)
Temporal distance (*rest of world*)			0.11	0.10
			(0.10)	(0.10)
Per. of distant impacts			1.17***	1.14***
			(0.10)	(0.10)
Gender				0.24
				(0.16)
Nationality				-0.15
				(0.33)
Constant	3.59***	1.01	-2.64***	-2.34***
	(0.52)	(0.85)	(0.73)	(0.75)
Observations	160	160	160	159
R2	0.24	0.37	0.66	0.68
Adjusted R2	0.22	0.34	0.64	0.66
Residual Std. Error	1.36 (df=155)	1.25 (df=153)	0.92 (df=151)	0.90 (df=148)
F statistic	11.97***	14.90***	36.68***	31.08***
	(df=4;155)	(df=6;153)	(df=8;151)	(df=10;148)
Note:				*p<0.1;**p<0.05;***p<0.01

Appendix XI. Regression analysis of factors affecting perceptions of distant impacts *(impacts on region, Spain, industrialised countries, developing countries, future generations and plant and animal species)*

	Dependent variable: perceptions of distant risks			
	Proximal (1)	**Proximal + Beliefs (2)**	**Proximal + Beliefs + Distant (3)**	**Full model incl. socio-demographics (4)**
Cognitive effort	0.03	0.02	0.03	0.05
	(0.03)	(0.03)	(0.03)	(0.03)
Concern	0.12***	0.08***	0.08***	0.08***
	(0.03)	(0.04)	(0.04)	(0.04)
Visited	-0.13	-0.12	-0.13	-0.17
	(0.11)	(0.11)	(0.11)	(0.11)
Temporal distance (*Spain*)	-0.001	0.01	0.08	0.08
	(0.04)	(0.04)	(0.05)	(0.05)
Perception of personal impacts	0.44***	0.40***	0.39***	0.39***
	(0.03)	(0.03)	(0.03)	(0.04)
Moral responsibility		0.06	0.04	0.02
		(0.06)	(0.06)	(0.06)
Climate importance		0.11**	0.10**	0.10**
		(0.05)	(0.05)	(0.05)
Temporal distance (*rest of world*)			-0.12*	-0.12**
			(0.06)	(0.06)
Gender				0.02
				(0.09)
Nationality				0.33*
				(0.19)
Constant	3.14***	2.56***	2.76***	2.52***
	(0.24)	(0.37)	(0.38)	(0.40)
Observations	160	160	160	159
R2	0.67	0.69	0.69	0.70
Adjusted R2	0.66	0.67	0.68	0.68
Residual Std. Error	0.55 (df=154)	0.54 (df=152)	0.53 (df=151)	0.53 (df=148)
F statistic	62.40***	47.39***	42.68***	34.93***
	(df=5;154)	(df=7;152)	(df=8;151)	(df=10;148)
Note:				*p<0.1;**p<0.05;***p<0.01

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Endnotes

[i] 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 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 and 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 Duesto 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.