



HAL
open science

Prevention of environmental risks : an experimental approach

Sarah van Driessche

► **To cite this version:**

Sarah van Driessche. Prevention of environmental risks : an experimental approach. Economics and Finance. Université de Lorraine, 2022. English. NNT : 2022LORR0199 . tel-04052360

HAL Id: tel-04052360

<https://hal.univ-lorraine.fr/tel-04052360v1>

Submitted on 30 Mar 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



**UNIVERSITÉ
DE LORRAINE**

**BIBLIOTHÈQUES
UNIVERSITAIRES**

AVERTISSEMENT

Ce document est le fruit d'un long travail approuvé par le jury de soutenance et mis à disposition de l'ensemble de la communauté universitaire élargie.

Il est soumis à la propriété intellectuelle de l'auteur. Ceci implique une obligation de citation et de référencement lors de l'utilisation de ce document.

D'autre part, toute contrefaçon, plagiat, reproduction illicite encourt une poursuite pénale.

Contact bibliothèque : ddoc-theses-contact@univ-lorraine.fr
(Cette adresse ne permet pas de contacter les auteurs)

LIENS

Code de la Propriété Intellectuelle. articles L 122. 4

Code de la Propriété Intellectuelle. articles L 335.2- L 335.10

http://www.cfcopies.com/V2/leg/leg_droi.php

<http://www.culture.gouv.fr/culture/infos-pratiques/droits/protection.htm>



UNIVERSITÉ
DE LORRAINE

SJPEG



BETA
Bureau
d'économie
théorique
et appliquée

Ecole Doctorale Sciences Juridiques, Politiques
Economiques et de Gestion (ED SJPEG)
Bureau d'Economie Théorique et Appliquée
(BETA)

Thèse

Présentée et soutenue publiquement pour l'obtention du titre de

DOCTEUR DE L'UNIVERSITE DE LORRAINE

en SCIENCES ECONOMIQUES

par **Sarah VAN DRIESSCHE**

Sous la direction de **Eve-Angéline LAMBERT** et **Julien JACOB**

Prevention of environmental risks: an experimental approach

5 décembre 2022

Membres du jury :

Directeurs de thèse :	M. Julien JACOB	Maître de conférences - HDR, Université de Strasbourg
	Mme Eve-Angéline LAMBERT	Professeur, Université de Lorraine
Président :	M. Sébastien MASSONI	Professeur, Université de Lorraine
Rapporteurs :	M. François COCHARD	Professeur, Université de Franche Comté
	Mme Astrid HOPFENSITZ	Professeur, EMLyon Business School
Examineurs :	M. Giuseppe ATTANASI	Professeur, Sapienza University of Rome
	Mme Lisette IBANEZ	Directrice de recherche INRAE, CEE-M, Université de Montpellier

Remerciements

Ici s'achèvent quatre années d'une expérience indescriptible. On pense souvent que la thèse est une aventure solitaire. Pourtant, je ne me suis jamais sentie aussi bien entourée.

En premier lieu, je souhaite adresser mes remerciements à mes directeurs de thèse, Eve-Angéline Lambert et Julien Jacob. D'une part, pour la confiance et la liberté qu'ils m'ont accordées dans la poursuite de mon travail de recherche et, d'autre part, pour les conseils qu'ils m'ont prodigués et grâce auxquels j'ai pu tant progresser.

Ensuite, je tiens à remercier les membres du jury. Tout d'abord, Madame Astrid Hopfensitz et Monsieur François Cochard qui m'ont fait l'honneur d'évaluer cette thèse. Ensuite, Madame Lisette Ibanez, Monsieur Giuseppe Attanasi et Monsieur Sébastien Massoni qui ont accepté d'être examinateurs. Je suis très honorée de vous compter parmi les membres du jury.

Je remercie aussi Agnès Gramain et Serge Garcia, les directeurs du Bureau d'Economie Théorique et Appliquée à Nancy, qui ont fait en sorte que je puisse réaliser ma thèse dans d'excellentes conditions. J'adresse également mes remerciements aux différents (ex-)membres de l'Ecole Doctorale, Monsieur Jean-Noël Ory, Monsieur Jochen Sohnle, Madame Eve-Angéline Lambert, Madame Sandrine Cecchi et Madame Juliette Barbat, qui mettent tout en œuvre pour accompagner au mieux les doctorants.

Mes remerciements vont ensuite à mes co-auteurs, Marielle Brunette, Kene Boun My et Mathieu Lefebvre, auprès de qui j'ai énormément appris. Je tiens à souligner l'aide que j'ai reçue de la part de Kene lors de la réalisation des différentes sessions expérimentales. Je souhaite, en particulier, remercier Mathieu car je ne serais pas ici sans lui. Au-delà de tout ce qu'il m'a appris sur le plan scientifique, je lui suis extrêmement reconnaissante du soutien qu'il m'a apporté durant les périodes plus compliquées.

J'adresse également mes remerciements aux membres de mon comité de suivi, Madame Lisette

Ibanez et Monsieur Olivier L'Haridon, qui ont veillé au bon déroulement de cette thèse.

Je souhaite ensuite remercier les différents enseignants-chercheurs du laboratoire qui, à un moment ou à un autre, ont lu un de mes chapitres, ont assisté à une (voire même plusieurs) de mes présentations, m'ont donné des conseils ou simplement aidée. Je dois ici mentionner Sébastien Massoni, Yannick Gabuthy, Serge Garcia, Cécile Bourreau-Dubois, Ankinée Kirakozian et Agnès Gramain.

Parce que le laboratoire serait un endroit bien moins chaleureux sans elles, je tiens à remercier Sylviane, Julie, Muriel et Touria qui nous font profiter de leur bonne humeur et de leur efficacité à toute épreuve.

Je souhaite aussi remercier les (jeunes) docteurs et doctorants que j'ai eu la chance de rencontrer pendant ces années de thèse. La légende dit qu'ils ne sont 'que' mes collègues, mais ça reste une légende... En premier lieu, je tiens à remercier les anciens doctorants qui étaient là à mon arrivée en thèse, Dylan qui m'a si bien accueillie et aidée, Camille qui a été, entre autres, ma partenaire sportive, Julien, Georges, Gaye et Jaune. Ensuite, je souhaite remercier mes compagnons de galère, Jaele, Jeanne et Julien, pour leur gentillesse, leur soutien et tous les bons moments passés ensemble. Je dois, ici, aussi mentionner Ankinée pour sa bienveillance et sa générosité. Je remercie également les membres du bureau Productivité, Morten, Tatiana, Vincent, Léa, Daniel, Seynabou et ceux qui n'ont pas eu le privilège de s'y trouver, Abdelkarim et Arthur, le duo comique. En particulier, j'adresse mes remerciements à Vincent pour ses différentes relectures et nos discussions animées (il n'a pas été facile de le convaincre de la supériorité des Belges). Finalement, je remercie mes collègues du campus AgroParisTech qui m'ont, à plusieurs reprises, chaleureusement accueillie parmi eux.

J'ai également une pensée pour les différentes personnes avec qui j'ai travaillé comme assistante de recherche à l'Université de Liège et qui m'ont donné le goût de la recherche.

Ensuite, je tiens à remercier mes amis qui ont toujours cru en moi. Leur soutien m'a été indispensable.

En particulier, je remercie Ysaline pour son aide dans le lancement de mon entreprise d'éoliennes. Plus sérieusement, je la remercie pour sa bienveillance et sa clairvoyance. J'ignore si elle le sait mais elle a été (et est toujours) un véritable pilier tout au long de ces années. Merci à Pauline pour son enthousiasme sans faille. Elle a toujours su se montrer encourageante et se réjouir pour moi (et parfois même plus que moi). Je remercie également Manon de m'avoir encouragée

maintes fois et d'avoir été une oreille attentive. Merci aussi aux deux mamans du groupe, Alysson et Natacha, qui ont toujours veillé à prendre de mes nouvelles, ainsi qu'aux Sara(h).

Je tiens à remercier Zoé qui a été ma plus grande supportrice durant ces quatre années, et notamment pendant ces derniers mois. Je ne saurais exprimer à quel point j'ai apprécié son soutien. Je souhaite aussi remercier les membres des Pookies, Raphael, Thomas, François, Basile et Loïc qui m'ont soutenue chacun à leur manière.

Je remercie, bien sûr, mon meilleur ami, Antoine, pour ses nombreux encouragements et sa bonne humeur à toute épreuve. Merci également à Gregory, mon coloc, et Caro. Je remercie mes deux acolytes, Thibaut et Grégoire, ainsi que Annie et Eric.

J'adresse mes remerciements à mes amies du basket, Angèle et ses filles, Valentine, Lydie, Caroline-Marie et Camille, ainsi qu'à toutes mes anciennes coéquipières que j'ai côtoyées durant ma (très prestigieuse) carrière.

Mes remerciements les plus sincères vont à mes parents, sans qui je ne serais pas là aujourd'hui. A bien des égards, ils m'ont été d'un soutien irréprochable. Je les remercie de m'avoir toujours encouragée à poursuivre ma formation. J'ai une pensée particulière pour ma maman qui voit (enfin) ses deux enfants terminer leurs études. Je remercie aussi mon frère, Pierre, qui m'a soutenue à sa façon bien à lui. Je pense également à mes grands-parents et, en particulier, à ma grand-mère qui n'a jamais bien compris l'intérêt d'avoir un Docteur dans la famille incapable de soigner les gens. Pourtant, elle s'est toujours souciée du bon déroulement de ma thèse et je l'en remercie. Même si je ne la vois pas souvent, je remercie aussi ma marraine pour ses nombreuses attentions.

Finalement, mais comme le dit l'expression "le dernier mais pas le moindre", je tiens à remercier Romain qui m'a accompagnée ces derniers mois et qui me comprend même quand je ne dis rien. Peu de personnes sont capables d'écouter les silences.

A ma grand-mère

Contents

List of Figures	4
List of Tables	5
Introduction	7
Bibliography of the Introduction	18
Appendix of the Introduction	24
0.A Single vs. double hull	24
Chapter 1	25
1.1 Introduction	27
1.2 Experimental design and predictions	31
1.2.1 Design	31
1.2.2 Model and predictions	34
1.3 Results	39
1.3.1 Procedure	39
1.3.2 Average contributions	40
1.3.3 Individual decisions	45
1.4 Discussion and conclusion	50
Bibliography of Chapter 1	53
Appendices of Chapter 1	57
1.A Proof of Prediction 1	57
1.B Distribution of contributions per treatment	58
1.C Econometric results	59

1.D	Instructions	60
Chapter 2		69
2.1	Introduction	71
2.2	Experimental design	74
2.2.1	Main game	74
2.2.2	Treatments	76
2.2.3	Inequality and risk preferences, environmental sensitivity	78
2.2.4	Procedure	79
2.3	Predictions	80
2.4	Results	83
2.4.1	Group contributions	83
2.4.2	Within-treatment comparisons	84
2.4.3	Between-treatment comparisons	87
2.4.4	Individual decisions	89
2.5	Discussion and conclusion	94
	Bibliography of Chapter 2	96
	Appendices of Chapter 2	102
2.A	Average contributions over time per treatment and type of subjects	102
2.B	Instructions	102
Chapter 3		119
3.1	Introduction	121
3.2	Experimental design	125
3.2.1	Main game	125
3.2.2	Treatments	126
3.2.3	Subjects' preferences	130
3.2.4	Procedure	131
3.3	Results	132
3.3.1	Average contributions	133
3.3.2	Individual decisions	138
3.4	Discussion and conclusion	145

Bibliography of Chapter 3	146
Appendices of Chapter 3	151
3.A Comparison of Classic and Environment subjects	151
3.B Instructions	152
Conclusion	167
Bibliography of the Conclusion	171

List of Figures

- 0.A Single vs. double hull 24
- 1.1 Average contributions over time per treatment 44
- 1.2 Average contributions combining all 5-period sequences 44
- 1.A Distribution of contributions per treatment 58
- 1.B Table 1 - Probability 64
- 1.C Table 2 - Loss 65
- 2.1 Average group contributions over time 85
- 2.A Average contributions over time per treatment and subjects type 102
- 2.B Adaptation table in T25 111
- 2.C Adaptation table in T15-55 112
- 3.1 Resulting probability in Risk 127
- 3.2 Resulting probabilities in Ambiguity 128
- 3.3 Average contributions to mitigation over time per treatment 136
- 3.A Adaptation table 159

List of Tables

1.1	Experimental treatments	33
1.2	Experimental treatments and parameters	36
1.3	Mean, minimum and maximum contributions per treatment (std. dev. in parentheses)	41
1.4	Variables definition	46
1.5	Tobit and logit estimations	47
1.A	Tobit estimations	59
2.1	Experimental treatments	76
2.2	Average group contributions to mitigation (std. dev. in parentheses)	83
2.3	Average contributions by subjects types (std. dev. in parentheses)	86
2.4	Inter-treatments pairwise comparisons (number of obs. in parentheses)	88
2.5	Variables definition	90
2.6	Linear and fractional probit estimations	91
3.1	Number of sessions and subjects per treatment	132
3.2	Mean, minimum and maximum contributions to mitigation (std. dev. in parentheses)	134
3.3	WTP and mean contributions according to the urn (std. dev. in parentheses)	137
3.4	Variables definition and descriptive statistics per treatment	139
3.5	Tobit estimations per treatment	141
3.6	Probit and linear regressions on the WTP in IA	143
3.A	Comparison of Classic and Environment subjects	151

Introduction

The recent developments of societies that take place through globalization, economic expansion, population growth, urban sprawl, etc., increasingly expose them to various risks (Grozavu and Mihai, 2018). In particular, they have become more vulnerable to environmental risks. Examples of such risks abound: the eruption of the Sakurajima volcano in Japan (July 2022), the recent earthquake of magnitude 7 in the Philippines (July 2022), the fire at the Lubrizol company in Rouen (France, September 2019), air pollution, climate change, etc. The greater intensity and frequency of those events call for collective action from governments and citizens.

Prior to defining environmental risks, it is worth precisizing the notion of risk itself. Usually, the risk is defined as the combination of two elements: the probability of an undesirable event and the adverse consequences of that event (Crocker and Shogren, 2003). The United Nations General Assembly gives the following definition of disaster risk: “the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity” (United Nations General Assembly, 2016, p. 14). Smith and Petley (2009) extend the concept to environmental risks and define them as: “extreme geophysical events, biological processes and technological accidents that release concentrations of energy or materials into the environment on a sufficiently large scale to pose major threats to human life and economic assets” (Smith and Petley, 2009, p. 12). In this thesis, we will mainly focus on reducing the probability that those environmental hazards occur.¹

Smith and Petley (2009) identify three different categories of environmental risks: the natural hazards, the technological hazards, and the context hazards. In this analysis, we will concentrate

¹While Smith and Petley (2009) and Grozavu and Mihai (2018) differentiate between hazard (the threat not the event itself) and risk (the probability of a hazard occurring and creating a disaster), we will use both terms interchangeably.

only on anthropogenic risks, so that we can actually influence the probability of occurrence of the disasters. Therefore, we will not cover the natural hazards (e.g., tropical cyclones, avalanches). The technological risks result mainly from major accidents (e.g., release of toxic material, train crashes) while the context hazards are embedded within global-scale processes (e.g., deforestation, climate change).

A famous example of a technological disaster is the large-scale maritime accident of the oil tanker Erika. The ship broke in 1999 off the coast of Brittany, spilling 20 000 tonnes of fuel in the sea. As a consequence, four hundreds of kilometers of the French coast were contaminated by heavy oil, more than 150 000 oiled birds perished and the economic damage amounted to 1 billion euros (Camproux-Duffrene and Guihal, 2013). The ship was chartered by the company Total which was aware of the poor state of the vessel. Despite this decrepitude, the classification society Rina certified that the boat complied with the requirements. While international maritime conventions limited liability to the owner, administrator, or captain; in 2012, Total and the classification society Rina were found liable for the wreck of the Erika and environmental degradation, as were the owner Savarese and the administrator Pollara. It was the first time in France that a court recognized the notion of *ecological loss*.² In 2013, this notion was laid down in the French Civil code and defined by article 1247.

Regarding context hazards, Landrigan et al. (2018) show that ambient air and chemical pollution drastically increase due to economic activities. Pollution jeopardizes the stability of human societies although it has been overlooked, especially in developing countries. Indeed, in a follow-up study using data from the Global Burden of Diseases, Injuries, and Risk Factors Study, Fuller et al. (2022) assert that, in 2019, air pollution was responsible for 6.7 millions of deaths. Over the past two decades the number of deaths due to modern forms of pollution (i.e., ambient air pollution and chemical pollution) has increased by 66%. It is also well known that air pollution is closely related to climate change (Kobayashi et al., 2014). The sixth assessment report of the IPCC³ (2021) assure that global warming is due to human influence and, in particular, to anthropogenic greenhouse gaz (GHG) emissions which have increased across all major sectors worldwide since 2010. As a result, many weather and climate extremes have become more likely. A recent example is the two heatwaves that hit Western Europe in the summer of 2019. In France,

²In French, it is a *préjudice écologique*.

³IPCC: Intergovernmental Panel of experts on Climate Change.

the temperature went up to 46°C near Nîmes. Vautard et al. (2020) prove that human influence drastically increases the frequency of these short and intense events and raises the temperatures by 1.5°C to 3°C for events of that frequency. These heatwaves were the deadliest disasters during the year 2019.

The above-mentioned examples speak for themselves, confirming the importance of limiting the frequency of these risks. In this thesis, we will attempt to find ways to reduce the likelihood of occurrence of environmental hazards. A common trait of these examples is that it is possible to *collectively* decrease such probability. In the case of the Erika tanker, developments were undertaken regarding ships' hull. More precisely, tankers should now be equipped with a double-hull structure rather than a single-hull structure (see Appendix 0.A). This way, in case of collision or grounding, the likelihood that toxic substances spill out decreases as the outer layer may be the only one to be damaged.⁴ On the other hand, measures can also be taken by classification companies. More thorough and frequent inspections of vessels should reduce the probability of such disasters occurring. In respect of climate change, it is obvious that GHG emissions can collectively be reduced, whether it is at a global level (e.g., countries by implementing a carbon tax) or at more local levels (e.g., cities by promoting public transport, individuals by using cleaner energy), in order to reduce the frequency of occurrence of weather and climate extremes. It is readily understandable that while parties bear a private cost to decrease the probability, they can benefit from this reduced likelihood, whether they actually contribute to it or not. There are therefore incentives to free ride, that is, to take advantage of other parties' contributions to decrease the probability without making any effort toward this goal. This is a classic collective action problem. Collective action was first studied in a seminal work by Olson (1965). It consists of a situation where efforts from several individuals are needed to reach a common objective (Sandler, 2004). The behavior of an individual depends on the contributions of others and thus collective action involves strategic interactions. Oftentimes, the socially optimal outcome is not fulfilled because of the rational individual decisions which lead to a sub-optimal collective choice. Therefore, full cooperation is hardly achievable in such situations. A well-known kind of collective action problem is the provision of public goods. A public good is non-rival and non-excludable. For example, reducing air pollution produces non-rival and non-excludable benefits since everyone can take advantage of a less polluted atmosphere and it is impossible to prevent someone from

⁴A good example of the efficiency of double-hull is the Nanny tanker which ran aground on a shoal in 2014.

breathing this cleaner air. The provision of public goods has been extensively investigated in the experimental literature (see Ledyard (1995) for an exhaustive survey on public good experiments and Chaudhuri (2011) for a more recent one). In a traditional linear public good game, subjects receive an endowment and must decide how much to contribute to a private account and to a public account. The per capita return from the public account is lower than the per capita return from the private account which is itself lower than the group return from the public account. Those conditions ensure that there exists a social dilemma in the sense that the dominant strategy of each subject is to make no contribution to the public account whereas the social optimum requires all subjects to invest their entire endowment in the public account (Villegal, 2012). While theory predicts no contribution to the public good, empirical results show that the provision of the public good is positive. The literature highlights the role of the beliefs about others' contributions and of social preferences in the decision to voluntarily contribute. Fischbacher and Gächter (2010) identify three different profiles of contributors which combine social preferences and conditionality. The altruists who invest, on average, all their endowment, the free-riders (*homo oeconomicus*) who do not contribute, and the conditional cooperators who reciprocate and conform to the norm (which is considered as the mean contribution to the public good).

Several experimental papers have tackled environmental issues using (modified) public good games, and some of them are of particular interest.⁵ Gangadharan and Nemes (2009) study the role of environmental risk and uncertainty. In some treatments, there is an exogenous risk of not getting the returns from either the private account or the public account. In other treatments, the probability of obtaining the benefits from either the private account or the public account is endogenous and unknown. It increases with the contributions of subjects in the respective accounts. Formerly, Dickinson (1998) introduced uncertainty about actually receiving the returns from the public good. In one treatment, the probability is equal to 70%, while in another one, it rises with total contributions.

However, while these experiments consider a risk of not getting the earnings from a public good, there is a significant difference compared with our context. Indeed, in those experiments, contributions aim at increasing the chances to receive a gain, while in this thesis, contributions

⁵Another kind of collective action problem which has been widely (experimentally) studied is the tragedy of the commons (Hardin, 1968). In that case, individual decisions imperil common pool resources (CPR) (e.g., fisheries, forests) because they lead to an overexploitation of those (manmade or natural) resources. See, for example, Gardner et al. (1990) for the first experiment on CPR dilemma, Walker and Gardner (1992); Blanco et al. (2016, 2017) for endogenous losses in appropriation game settings.

serve to reduce the chances to incur a loss. This is what will be defined as a *public bad* in the rest of this analysis. Contrary to a public good for which the goal is to increase its provision, for a public bad, the objective is to reduce or to avoid it. The notion of public bad has been used in different contexts. For example, in Ostrom (2010), combating climate change must serve to reduce the threats of global bads (e.g., increased ocean levels, increased variability in climate patterns). Dannenberg et al. (2015) define a public bad as an undesirable event which must be collectively prevented. Boucher and Bramoullé (2010) consider GHG emissions as a global public bad and focus on the reduction of its production. In this thesis, we will turn our attention to the prevention of public bads through a collective reduction in their probability of occurrence.

Numerous experimental papers related to environmental issues have explored the behavior of subjects when they are jointly threatened by a loss.⁶ Hasson et al. (2010) utilize a public good game to represent the trade-off between mitigation and adaptation to climate change. Subjects, in groups of four, can decide either to mitigate or to adapt. If they invest in mitigation, it reduces the probability of occurrence of a climate damage for each group member, while if they decide to contribute to adaptation, it decreases the size of the loss for themselves only. Between treatments, the authors modify the initial size of the loss subjects may incur in case of a climatic event. In a similar experiment, Hasson et al. (2012) compare a probabilistic treatment to a deterministic one. The former situation is similar to the experiment by Hasson et al. (2010). In the latter case, the climate event occurs with certainty. Therefore, both measures allow for a reduction in the size of the loss. Investments in mitigation decrease the magnitude of the damage for everyone in the group, while investments in adaptation reduce the size of the loss for the subject only. McEvoy et al. (2022) also study social dilemmas with mitigation and adaptation. They look at the effect of non-binding pledges (i.e., subjects announce their intended mitigation contribution) in a treatment where subjects can only mitigate, and in a treatment where subjects can both mitigate and adapt. Blanco et al. (2020) study the use of public and private insurance when there is a risk of loss at the group level. More precisely, subjects, in groups of four, can decide to invest their endowment in a public insurance to reduce the probability of a loss occurring for the

⁶Two relevant papers on this topic are Köke et al. (2015) and Gsottbauer et al. (2018). Köke et al. (2015) investigate the behavior of subjects who can decide to cooperate in order to reduce either the probability or the size of a common damage. Gsottbauer et al. (2018) concentrate on financial compensation for climate damage. In a group comprised of one rich and one poor, there is the possibility for both of them to reduce the likelihood that the poor subject incurs a loss. If the damage occurs, the liability of the rich subject depends on the treatment. However, in both papers, the authors use a prisoner dilemma game. Given our continuous action space, we decide to focus more closely on public good game settings.

whole group, in a private insurance to reduce the severity of the loss for themselves only, or in a non-insurance fund to earn private gains. Between treatments, the authors vary the size of the loss. Furthermore, they also compare a probabilistic situation and a deterministic one (the loss is certain). Flambard et al. (2020) compare a deterministic and probabilistic public good game to a deterministic and probabilistic public bad game. More specifically, subjects, in groups of three, must decide on the allocation of their balls between two different urns. In the deterministic public good game, a ball placed in either urn generates a benefit (either for the subject or for each group member), while in the deterministic public bad game, it generates a loss. However, in the probabilistic public good game, putting a ball in a specific urn increases the chances of a collective gain, while in the probabilistic public bad game, it decreases the probability of a collective loss. In Keser and Montmarquette (2008), subjects, in groups of three, can decide to invest their tokens in a private account to increase their own payoffs, or to invest them in a group account. Each token invested in the group account reduces the probability that a loss affects all the group members equally. The authors investigate the impact of modifying the initial wealth, the size of the loss and the *ex ante* probability of the loss. Furthermore, they look at the impact of introducing ambiguity with regard to the *ex ante* probability and the efficiency of a token invested in the group account.

A great number of studies have focused on threshold public good games wherein the provision of the public good must reach a given level in order to avoid a collective loss. These studies are motivated by the worsening of climate change. Milinski et al. (2008) run an experiment where subjects can decide to invest their resources in a climate account, or in a private account whose returns are guaranteed only if the climate account reaches a threshold. If the target is not met, there is a risk that subjects lose all their savings. This is what they identify as a “collective-risk social dilemma”. Between treatments, the authors modify the probability of incurring a loss. Several papers have examined the role of inequalities in collective-risk social dilemmas. In an experiment similar to that of Milinski et al. (2008), Milinski et al. (2011) look at the effect of wealth heterogeneity, that is, they constitute groups of rich subjects, groups of poor subjects and mixed groups (with rich and poor subjects). In addition to studying the role of inequality, Tavoni et al. (2011) allow subjects to communicate their intended contribution. Burton-Chellew et al. (2013) study the effect of endowment heterogeneity. More precisely, between treatments, they redistribute the group endowment among group members, such that in one treatment,

endowments are the same for each group member, and in another one, there are two rich subjects and four poor subjects within a group. Moreover, the authors vary the risk exposure of subjects depending on whether they are rich or poor. Vasconcelos et al. (2014) address the issue of wealth inequality and assess the role of homophily. The latter refers to the fact that the behavior of rich (poor) subjects is influenced only by rich (poor) subjects and not by poor (rich) ones. Brick and Visser (2015) concentrate on five specific regions (US, China, India, European Union (EU), South Africa) which were, in 2006, responsible for 62% of global GHG emissions. In their experiment, the groups are comprised of one subject from each region. Subjects from developed countries (US and EU) receive a larger endowment than those from developing countries. Each subject must choose one of the four equity principles which define the contribution obligations to the threshold public good. If subjects do not manage to meet the target, they get nothing from the public good and lose a part of their endowment that depends on the region to which they belong. By comparing a treatment where subjects represent their own region in the group, to another treatment where they do not, the authors want to learn if the choice of an equity principle is self-interested in the first treatment. Other papers have focused on the effects of uncertainty and ambiguity in collective-risk social dilemmas. Barrett and Dannenberg (2012) look at the effect of bringing in uncertainty about the value of the target (located within a known range of values), and about the value of the loss (located within a known range of values) in case the threshold is not reached. In a similar experiment, Barrett and Dannenberg (2014) compare different treatments by varying the range of values within which the threshold is located. Dannenberg et al. (2015) introduce complete ambiguity regarding the threshold. That is, subjects not only ignore the value of the threshold but are also unaware of its probability distribution.

Some experiments are also relevant for this analysis although there are some discrepancies in their design.⁷ In particular, two papers have concentrated on collectively reducing the magnitude of the loss rather than its probability of occurrence. Boun My and Ouvrard (2019) look at the efficiency of implementing a tax or a nudge in an environmental public good game. Subjects

⁷Other papers also focus on collectively reducing the probability of a loss but not in an environmental context. For example, Martin-Lapoirie (2021) studies the behavior of two health care professionals who can take precautions in order to decrease the probability of medical malpractice. Füllbrunn and Neugebauer (2013) examine the safety net problem as a social dilemma. However, instead of pooling contributions to reduce the probability of a common loss, the authors actually pool the individual losses that occurred after individual decisions, so that those losses can be apportioned among group members according to the treatment. Kornhauser and Schotter (1992) study bilateral accidents. Both the victim and the injurer can make costly investments in order to reduce the probability that the victim incurs a loss. The authors investigate the effects of different liability rules on the levels of precaution.

must decide on the allocation of their tokens between a private account and an environmental account. A token contributed to the latter reduces the level of pollution for each group member. By investing in the environmental account, subjects can thus decrease the loss of utility due to pollution. Jacob et al. (2022) study the performance of liability rules in case of environmental harms caused by several firms. Subjects, in groups of two, can make costly investments in order to reduce the magnitude of the common damage (which is certain). They are both liable for half of the remaining harm. Between treatments, the authors modify the degree of solvency of the subjects (i.e., both solvent, both insolvent, one solvent and one insolvent). Depending on the liability rule, the wealthier subject can also have to pay for a part of the other firm's share of liability. Angelova et al. (2014) also study the efficiency of liability rules for managing environmental harms. However, they consider only one tortfeasor. Subjects, in groups of two, represent either the injurer or the victim. The injurer can decide to invest part of their endowment in safety in order to reduce the probability of an accident occurring. In case of an accident, the victim (which represents the environment) loses all their endowment and, depending on the liability rule in place, the tortfeasor is held liable for repairing the damage. Attanasi et al. (2020) experimentally investigate the behavior of a firm and an insurer-company when the firm can not only make costly investment in safety in order to reduce the probability of a technological damage but can also take out an insurance contract to protect itself against the consequences of the disaster. After acknowledging the insurance offer from the insurer-company, the firm must choose simultaneously its level of precaution and whether or not it buys insurance.

Despite the wide variety of designs, all of these papers share the feature of facing common losses. In this thesis, we will concentrate on avoiding public bads by collectively decreasing the probability of occurrence of those undesirable events. More specifically, the focus will be on environmental risks since they have become harsher. Different strategies to achieve this goal will be explored through the three chapters of this thesis. In the first chapter, we will consider technological risks. A good working example could be several firms located along a river which can potentially pollute it and thus create an environmental damage. The objective of this chapter will be to find efficient incentives to induce the firms to invest in safety in order to avoid environmental harms. In the second and third chapters, we will focus on context hazards, and more specifically on the risk of climate change. In these chapters, the analysis will be carried out at the individual level. In the second chapter, we will investigate the role of inequalities while the third chapter

will be devoted to the impact of ambiguity in the fight against climate change. These chapters aim at providing recommendations in order to foster cooperation within those specific contexts. The use of experimental economics seems particularly relevant to address these issues. Indeed, it is sometimes difficult to observe certain situations in reality because they only occur when very specific conditions are met or if certain public policies are implemented. In the absence of existing empirical data, laboratory experiments provide controlled environments in which institutions and policy components can be analyzed in a simplified setting in order to precisely measure their effects. Moreover, by making *ceteris paribus* changes in the variables, it is possible to isolate the causal links.

The goal of the **first chapter** is to prevent technological risks. One tool which is increasingly used to discourage environmentally damaging behaviors is *information disclosure*. It is defined by Tietenberg (1998) as “public and/or private attempts to increase the availability of information on pollution to workers, consumers, shareholders, and the public at large” (Tietenberg, 1998, p. 588). However, in case of environmental harms, information disclosure can only complement civil liability rules. Civil liability is the legal responsibility of paying money for damage to a victim. Considering environmental degradation, the defendant is then liable to finance the clean-up costs of hazardous sites. In cases where there are several tortfeasors, civil liability rules determine the apportionment of the damage among them. Two rules are mainly used to share liability: the per capita rule in the EU and the proportional rule in the US (especially in CERCLA⁸). Therefore, in this chapter, we investigate the efficiency of information disclosure combined with either a per capita rule or a proportional rule in order to prevent technological disasters. To do so, we propose an original experiment in which subjects, in groups of four, can make costly investments to reduce the probability of an environmental damage occurring. If it arises, the loss is shared between the four members according to the liability rule. Under a per capita rule, each group member bears one quarter of the loss, while under a proportional rule, the share of liability depends on the relative investments in safety. In the first two treatments, we introduce information disclosure by publicly displaying the worst contributors, under a per capita rule (one treatment) and under a proportional rule (another treatment). In order to evaluate the impact of the disclosure mechanism, we run two additional treatments without information disclosure. The results show that the efficiency of this disclosure strategy depends on the existing liability

⁸CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act.

rule. Indeed, under a per capita rule, information disclosure has a positive impact on the level of precaution. However, this does not hold true under a proportional rule: information disclosure has no impact. Another result which has interesting policy implications is that there is no significant difference in the levels of investments between a per capita rule with information disclosure and a proportional rule alone.

Relying on Hasson et al. (2010, 2012), the **second chapter** looks at how individuals deal with the risk of climate change in presence of inequalities. As evidenced by Ostrom (2010), even though the effects of climate change appear mainly at a global level, we need not to understate the importance of individual efforts. Vandenbergh and Steinemann (2007); Gardner and Stern (2008); Dietz et al. (2009) highlight the decisive role households can have in coping with climate change, in particular by reducing their GHG emissions. Therefore, we find it relevant to address this issue from an individual perspective. A crucial concern when facing global warming is the existence of within-country inequalities. The sixth assessment report of the IPCC (2021) ensures that the most vulnerable people are disproportionately affected by the adverse consequences of climate change. In a context of rising income inequalities (Alvaredo et al., 2017), we therefore assess the impact of such inequalities on the individual decision-making process related to climate change. To that end, we run a contextualized experiment in which subjects, in groups of four, must decide on the allocation of their endowment between mitigation and adaptation. Investments in mitigation allow for a reduction in the probability of a climate event for all the group members, while contributions to adaptation serve to reduce the severity of the climatic disaster only for the subject who chooses to adapt. Between treatments, we modify the distribution of endowments among group members, so as to increase the degree of inequality. As in Vasconcelos et al. (2014), we consider groups exhibiting an asymmetric distribution of rich and poor to reflect the current status of nations. We find that group contributions to mitigation do not depend on the treatment condition. At the individual level, rich subjects invest more than poor ones in absolute terms but not in proportion of their endowment. We also highlight the crucial role of social preferences among rich subjects in explaining their choice to mitigate.

The **third chapter** constitutes an extension of the second one. We still look at the trade-off between mitigation and adaptation, except that, in this chapter, we take into consideration the role of uncertainty that surrounds climate change. Despite the considerable work of scientists and researchers on this subject, a lot of uncertainties remain. A striking example of that is the

five different scenarios presented by the Working Group I of the IPCC (Etner et al., 2020). Each one of them represent a plausible evolution of the future world. Considering this particular context, we run a contextualized experiment to study the individual decisions to mitigate or to adapt to climate change in a risky context and in an ambiguous one. Subjects, in groups of four, are asked to invest their endowment in mitigation and/or adaptation policies. In the treatment Risk, they are perfectly aware of the probability of occurrence of the climate event. However, in the treatment Ambiguity, subjects do not perfectly know the probability of a climatic disaster occurring, in such a way that they are dealing with climate change in an ambiguous context. In the treatment Information Acquisition, subjects have the possibility to pay to obtain information, allowing them to go from an ambiguous situation to a risky one. The results suggest that average contributions to mitigation are not affected by the treatment conditions. Individual decisions to mitigate or to adapt are influenced by subjects' preferences toward risk and ambiguity. Ambiguity preferences also explain the intensity of the willingness to pay to obtain information.

By means of these three chapters, this thesis tries to come up with policy recommendations in order to collectively reduce the probability of occurrence of environmental risks. Reducing the frequency of such risks is a major challenge that societies need to address.

Bibliography of the Introduction

- Alvaredo, F., Chancel, L., Piketty, T., Saez, E., and Zucman, G. (2017). Global Inequality Dynamics: New Findings from WID.world. *American Economic Review*, 107(5):404–409.
- Angelova, V., Armantier, O., Attanasi, G., and Hiriart, Y. (2014). Relative performance of liability rules: experimental evidence. *Theory and Decision*, 77(4):531–556.
- Attanasi, G., Concina, L., Kamaté, C., and Rotondi, V. (2020). Firm’s protection against disasters: are investment and insurance substitutes or complements? *Theory and Decision*, 88(1):121–151.
- Barrett, S. and Dannenberg, A. (2012). Climate negotiations under scientific uncertainty. *Proceedings of the National Academy of Sciences*, 109(43):17372–17376.
- Barrett, S. and Dannenberg, A. (2014). Sensitivity of collective action to uncertainty about climate tipping points. *Nature Climate Change*, 4(1):36–39.
- Blanco, E., Dutcher, E. G., and Haller, T. (2020). Social dilemmas with public and private insurance against losses. *Journal of Economic Behavior & Organization*, 180:924–937.
- Blanco, E., Haller, T., and Walker, J. M. (2017). Externalities in appropriation: responses to probabilistic losses. *Experimental Economics*, 20(4):793–808.
- Blanco, E., Lopez, M. C., and Walker, J. M. (2016). The Opportunity Costs of Conservation with Deterministic and Probabilistic Degradation Externalities. *Environmental and Resource Economics*, 64(2):255–273.
- Boucher, V. and Bramoullé, Y. (2010). Providing global public goods under uncertainty. *Journal of Public Economics*, 94(9):591–603.
- Boun My, K. and Ouyard, B. (2019). Nudge and tax in an environmental public goods experiment: Does environmental sensitivity matter? *Resource and Energy Economics*, 55:24–48.
- Brick, K. and Visser, M. (2015). What is fair? An experimental guide to climate negotiations. *European Economic Review*, 74:79–95.

- Burton-Chellew, M. N., May, R. M., and West, S. A. (2013). Combined inequality in wealth and risk leads to disaster in the climate change game. *Climatic Change*, 120(4):815–830.
- Camproux-Duffrene, M.-P. and Guihal, D. (2013). Préjudice écologique. *Revue juridique de l'environnement*, 38(3):457–480.
- Chaudhuri, A. (2011). Sustaining Cooperation in Laboratory Public Goods Experiments: A Selective Survey of the Literature. *Experimental Economics*, 14:47–83.
- Crocker, T. D. and Shogren, J. F. (2003). Choosing Environmental Risks. In Folmer, H. and Tietenberg, T., editors, *The International Yearbook of Environmental and Resource Economics 2003/2004*. Edward Elgar Publishing.
- Dannenberg, A., Löschel, A., Paolacci, G., Reif, C., and Tavoni, A. (2015). On the Provision of Public Goods with Probabilistic and Ambiguous Thresholds. *Environmental and Resource Economics*, 61(3):365–383.
- Dickinson, D. L. (1998). The voluntary contributions mechanism with uncertain group payoffs. *Journal of Economic Behavior & Organization*, 35(4):517–533.
- Dietz, T., Gardner, G. T., Gilligan, J., Stern, P. C., and Vandenberg, M. P. (2009). Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. *Proceedings of the National Academy of Sciences*, 106(44):18452–18456.
- Etner, J., Jeleva, M., and Raffin, N. (2020). Climate policy: How to deal with ambiguity? *Economic Theory*, 72(1):263–301.
- Fischbacher, U. and Gächter, S. (2010). Social Preferences, Beliefs, and the Dynamics of Free Riding in Public Goods Experiments. *American Economic Review*, 100(1):541–556.
- Flambard, V., Le lec, F., and Romaniuc, R. (2020). How does risk affect collective participation? Public good provision versus public bad prevention. Mimeo.
- Fuller, R., Landrigan, P. J., Balakrishnan, K., Bathan, G., Bose-O'Reilly, S., Brauer, M., Caravanos, J., Chiles, T., Cohen, A., Corra, L., Cropper, M., Ferraro, G., Hanna, J., Hanrahan, D., Hu, H., Hunter, D., Janata, G., Kupka, R., Lanphear, B., Lichtveld, M., Martin, K., Mustapha, A., Sanchez-Triana, E., Sandilya, K., Schaeffli, L., Shaw, J., Seddon, J., Suk, W., Téllez-Rojo,

- M. M., and Yan, C. (2022). Pollution and health: a progress update. *The Lancet Planetary Health*, 6(6):e535–e547.
- Füllbrunn, S. and Neugebauer, T. (2013). Limited liability, moral hazard, and risk taking: a safety net game experiment. *Economic Inquiry*, 51(2):1389–1403.
- Gangadharan, L. and Nemes, V. (2009). Experimental analysis of risk and uncertainty in provisioning private and public goods. *Economic Inquiry*, 47(1):146–164.
- Gardner, G. T. and Stern, P. C. (2008). The Short List: The Most Effective Actions U.S. Households Can Take to Curb Climate Change. *Environment: Science and Policy for Sustainable Development*, 50(5):12–25.
- Gardner, R., Ostrom, E., and Walker, J. M. (1990). The Nature of Common-Pool Resource Problems. *Rationality and Society*, 2(3):335–358.
- Grozavu, A. and Mihai, F.-C. (2018). Introductory chapter: environmental risks between conceptualization and action. In *Environmental Risks*. IntechOpen.
- Gsottbauer, E., Gampfer, R., Bernold, E., and Delas, A.-M. (2018). Broadening the scope of loss and damage to legal liability: an experiment. *Climate Policy*, 18(5):600–611.
- Hardin, G. (1968). The Tragedy of the Commons. *Science*, 162(3859):1243–1248.
- Hasson, R., Löfgren, A., and Visser, M. (2010). Climate change in a public goods game: Investment decision in mitigation versus adaptation. *Ecological Economics*, 70:331–338.
- Hasson, R., Löfgren, A., and Visser, M. (2012). Treatment Effects of Climate Change Risk on Mitigation and Adaptation Behaviour in an Experimental Setting. *South African Journal of Economics*, 80(3):415–430.
- Jacob, J., Lambert, E.-A., and Garcia, S. (2022). Efficiency of Liability-Sharing Rules: An Experimental Case. *Journal of Institutional and Theoretical Economics*, 178(1):1–42.
- Keser, C. and Montmarquette, C. (2008). Voluntary contributions to reduce expected public losses. *Journal of Economic Behavior & Organization*, 66(3-4):477–491.

- Kobayashi, M., Yoshiura, S., Sato, T., and Kaneko, N. (2014). Managing Environmental Risks and Promoting Sustainability, Scientific Advancement, and Leadership Development. In Kaneko, N., Yoshiura, S., and Kobayashi, M., editors, *Sustainable Living with Environmental Risks*. Springer Japan, Tokyo.
- Kornhauser, L. A. and Schotter, A. (1992). An Experimental Study of Two-Actor Accidents. Working Paper, C.V. Starr Center for Applied Economics, New York University.
- Köke, S., Lange, A., and Nicklisch, A. (2015). Adversity is a school of wisdom: Experimental evidence on cooperative protection against stochastic losses. Technical Report 22, University of Hamburg, Faculty of Business, Economics and Social Sciences, WISO Research Laboratory.
- Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N. N., Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin, K., Mathiasen, K. V., McTeer, M. A., Murray, C. J. L., Ndahimananjara, J. D., Perera, F., Potočnik, J., Preker, A. S., Ramesh, J., Rockström, J., Salinas, C., Samson, L. D., Sandilya, K., Sly, P. D., Smith, K. R., Steiner, A., Stewart, R. B., Suk, W. A., van Schayck, O. C. P., Yadama, G. N., Yumkella, K., and Zhong, M. (2018). The Lancet Commission on pollution and health. *The Lancet*, 391(10119):462–512.
- Ledyard, J. O. (1995). Public Goods: A Survey of Experimental Research. In Kagel, J. H. and Roth, A. E., editors, *The handbook of experimental economics*, pages 111–194. Princeton University Press, Princeton, New Jersey, NJ.
- Martin-Lapoirie, D. (2021). Teamwork in health care and medical malpractice liability: an experimental investigation. *European Journal of Law and Economics*.
- McEvoy, D. M., Haller, T., and Blanco, E. (2022). The Role of Non-Binding Pledges in Social Dilemmas with Mitigation and Adaptation. *Environmental and Resource Economics*, 81(4):685–710.
- Milinski, M., Röhl, T., and Marotzke, J. (2011). Cooperative interaction of rich and poor can be catalyzed by intermediate climate targets: A letter. *Climatic Change*, 109(3-4):807–814.

- Milinski, M., Sommerfeld, R. D., Krambeck, H.-J., Reed, F. A., and Marotzke, J. (2008). The collective-risk social dilemma and the prevention of simulated dangerous climate change. *Proceedings of the National Academy of Sciences*, 105(7):2291–2294.
- Olson, M. (1965). *The Logic of Collective Action. Public goods and the theory of groups*. Harvard University Press, Cambridge, MA.
- Ostrom, E. (2010). A multi-scale approach to coping with climate change and other collective action problems. *Solutions*, 1(2):27–36.
- Prabowo, A., Laksono, F., and Sohn, J. M. (2020). Investigation of structural performance subjected to impact loading using finite element approach: Case of ship-container collision. *Curved and Layered Structures*, 7:17–28.
- Sandler, T. (2004). “With a little help from my friends”: principles of collective action. In *Global Collective Action*. Cambridge University Press, New York, NY.
- Smith, K. and Petley, D. N. (2009). Hazard in the environment. In *Environmental hazards: assessing risk and reducing disaster*. Routledge, New York, NY, 5th edition.
- Tavoni, A., Dannenberg, A., Kallis, G., and Loschel, A. (2011). Inequality, communication, and the avoidance of disastrous climate change in a public goods game. *Proceedings of the National Academy of Sciences*, 108(29):11825–11829.
- Tietenberg, T. (1998). Disclosure Strategies for Pollution Control. *Environmental and Resource Economics*, 11(3):587–602.
- United Nations General Assembly, U. N. G. A. (2016). Report of the Open-ended Intergovernmental Expert Working Group on Indicators and Terminology relating to Disaster Risk Reduction. Technical report.
- Vandenbergh, M. P. and Steinemann, A. C. (2007). The Carbon-Neutral Individual. *New York University Law Review*, 82:1673–741.
- Vasconcelos, V. V., Santos, F. C., Pacheco, J. M., and Levin, S. A. (2014). Climate policies under wealth inequality. *Proceedings of the National Academy of Sciences*, 111(6):2212–2216.

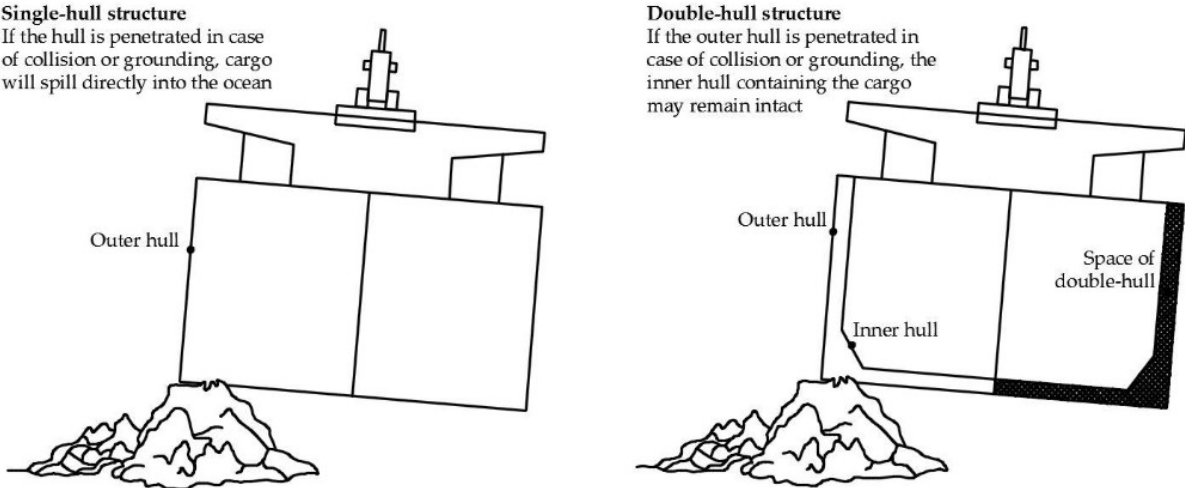
Vautard, R., van Aalst, M., Boucher, O., Drouin, A., Haustein, K., Kreienkamp, F., van Oldenborgh, G. J., Otto, F. E. L., Ribes, A., Robin, Y., Schneider, M., Soubeyroux, J.-M., Stott, P., Seneviratne, S. I., Vogel, M. M., and Wehner, M. (2020). Human contribution to the record-breaking June and July 2019 heatwaves in Western Europe. *Environmental Research Letters*, 15(9):094077.

Villeval, M. C. (2012). Contribution aux biens publics et préférences sociales: Apports récents de l'économie comportementale. *Revue économique*, 63(3):389–420.

Walker, J. M. and Gardner, R. (1992). Probabilistic Destruction of Common-pool Resources: Experimental Evidence. *The Economic Journal*, 102(414):1149–1161.

Appendix 0.A Single vs. double hull

Figure 0.A: Single vs. double hull



Source: Prabowo et al. (2020)

Chapter 1

Information disclosure under liability: an experiment on public bads

Julien Jacob, Eve-Angéline Lambert, Mathieu Lefebvre & Sarah Van Driessche

We experimentally investigate the impact of information disclosure on managing collective harms that are caused jointly by a group of liable agents. Subjects interact in a public bad setting and must choose *ex ante* how much to contribute in order to reduce the probability of causing a common damage. If a damage occurs, subjects bear a part of the loss according to the liability sharing rule in force. We consider two existing rules: a per capita rule and a proportional rule. Our aim is to analyze the relative impact of information disclosure under each rule. We show that information disclosure increases contributions only under a per capita rule. This result challenges the classical results regarding the positive effects of information disclosure, since we show that this impact may depend upon the legal context. We also show that while a proportional rule leads to higher contributions than a per capita one, the positive effect of disclosure on a per capita rule makes it as efficient as a proportional rule without information disclosure.

Contents

1.1	Introduction	27
1.2	Experimental design and predictions	31
1.2.1	Design	31
1.2.2	Model and predictions	34
1.3	Results	39
1.3.1	Procedure	39
1.3.2	Average contributions	40
1.3.3	Individual decisions	45
1.4	Discussion and conclusion	50
	Bibliography of Chapter 1	53
	Appendices of Chapter 1	57
1.A	Proof of Prediction 1	57
1.B	Distribution of contributions per treatment	58
1.C	Econometric results	59
1.D	Instructions	60

1.1 Introduction

Programs that disclose information about firms' environmental performance are increasingly used as a "third wave" to regulate pollution, in addition to market-based and command-and-control instruments. Disclosure strategies include public and/or private attempts to make information on pollution available to consumers, workers, shareholders and the public at large (Tietenberg, 1998). These programs are many and varied. Prominent examples of public disclosure include, among others, the Toxic Release Inventory (TRI) and the Greenhouse Gas Reporting Program (GHGRP), but other programs have emerged since in many countries, such as in India with the Green Rating Project (GRP) (Powers et al., 2011), or more recently in the European Union.¹ At local level, information disclosure may be public (e.g., livestreaming pollution disclosure, see Huet-Vaughn et al., 2018), or private when disseminated by non-governmental organizations or even citizens (Pien, 2020).

Information disclosure is a particularly interesting tool for several reasons. First, from a political viewpoint, disclosure is more acceptable than some direct regulations perceived as more coercive (Schatz, 2008). Second, the impact of disclosure programs is widely recognized in the literature as a way of decreasing pollution significantly, especially through the enforcement of performance evaluation, rating programs and toxic release inventories. Several studies have highlighted a positive impact of such programs on pollution abatement (see e.g., Blackman et al., 2004; Garcia et al., 2007; Benneer and Olmstead, 2008; Garcia et al., 2009; Powers et al., 2011; Huet-Vaughn et al., 2018). Finally, the cost incurred by countries may be low, as the information gathering cost can be borne by civil society (Jacquet and Jamieson, 2016). These advantages explain why information disclosure, although underutilized as a policy tool for a time (Schatz, 2008), has been increasingly debated and has often been included in countries' strategies to prevent environmental harms, both at national and local levels.

However, information disclosure mechanisms are additional to existing regulatory measures. In the case of pollution incidents or environmental accidents, information disclosure complements existing regulations based on civil liability. Civil liability in general, and in the environmental field in particular, allows third parties to be compensated and/or the clean-up costs of hazardous sites to be financed *ex post*, as well as providing incentives to invest *ex ante* in safety measures

¹See e.g., Directive 2018-851.

to avoid harms. In practice, two different rules of apportionment of liability “*ex post* financing” exist: a per capita rule and a proportional rule. According to the per capita rule, which is in force in most European countries, each of the n contributors has to compensate for $1/n$ of the common damage. Regarding the proportional rule which is used in the US, and especially in CERCLA², the share each contributor has to pay negatively depends on their relative investment in avoiding harm, compared to the investments of the others.³ The relevant question in this case is whether information disclosure enhances the efficiency of liability rules in *ex ante* investment in safety, and if so, whether this impact is dependent upon the liability rule that applies.

The aim of this chapter is to investigate the impact of information disclosure on investments that firms might make to avoid the occurrence of a damage, knowing that if harm does occur, liability rules apply. To this end, we conduct a laboratory experiment to analyze incentives to make investments in safety. We adopt a public bad setting in which players can contribute to reducing the probability of a fixed common loss, which is shared (through the apportionment of liability) among the group members if it occurs. The first two treatments introduce information disclosure through a so-called “identification mechanism”⁴ targeting the lowest contributors, under the liability rule in place, that is, either per capita (in one treatment) or proportional (in another one). In order to identify the relative impact of disclosure on investments, we run two additional treatments with the same two liability rules, but without disclosure. Our experimental design is thus well suited to take into account the fact that most environmental harms are caused by a multitude of agents. A recent example is the pollution of England’s rivers by water companies. Those firms are allowed to discharge untreated waste water only in exceptional circumstances (e.g., after extreme rainfalls) to relieve pressure in the sewerage system. However, data shows that in 2019 and in 2020, the amount of sewage released by water companies was far beyond the normal quantity. In such situations, civil liability must apportion liability among the multiple injurers who contributed to a single common damage.

Our results show that while a proportional liability rule leads to higher investments than a per capita rule, the introduction of a disclosure mechanism significantly increases investments only

²CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act. Section 113(f) of CERCLA allows for proportional liability in case of indivisible harm (see e.g., Kornhauser and Revesz, 1989; Pinkowski, 1996; Ferrey, 2009). An example is the Colorado vs. ASARCO, Inc case in 1985.

³Note here that if each tortfeasor invests the same amount, then the two rules are obviously equivalent.

⁴Note that the terms “recognition mechanism” and “naming mechanism” could also have been used, instead of “identification mechanism”.

under a per capita rule. A per capita rule combined with information disclosure would appear to be as efficient as a proportional rule without information disclosure.

The fact that the impact of disclosure is higher under a per capita rule than under a proportional rule can be explained by a higher social cost from being recognized as a low contributor under a per capita rule than under a proportional one. With a proportional rule, a low investment in the prevention of the risk results in a higher share of the loss to be paid in case of a damage occurring. To some extent, the worst contributors pay a “fair-share”, relative to their contribution to the expected harm: a polluter-pays principle somehow applies. The worst contributors take responsibility for their decisions. Under per capita, this mechanism cannot come into play as shares are independent of contributions, so that a low contribution imposes a high externality on other contributors. In that case, a low contribution can be perceived as a signal of being a free rider.

This chapter is thus closely related to the recent literature on the effects of information disclosure on firms’ environmental performance. Most of these papers study the enforcement of information disclosure and conclude that there is a positive impact (Blackman et al., 2004; Powers et al., 2011; Huet-Vaughn et al., 2018; Pien, 2020). Foulon et al. (2002) propose an original contribution by empirically analyzing the impact of fines and penalties on the one hand, and the impact of information disclosure on the other hand. They find that disclosure creates additional incentives for pollution control. Our findings partly challenge this result as we find mixed results as to the impact of disclosure, depending on which liability rule applies.⁵ Although field data used in these studies provide useful information, they do not allow endogeneity issues related to the different legal contexts and environmental issues to be avoided. Our experimental design allows us both to distinguish the impact of disclosure on subjects’ behavior and to compare the liability rules with (and without) disclosure. Obviously, such a 2x2 design could hardly be found in the field. Our chapter is also partly in line with the literature on public goods and the identification of contributors, with the latter being enforced through what is referred to as *naming and shaming* low contributors. A series of public goods experiments have shown that naming contributors by revealing their identity affects contribution levels (Andreoni and Petrie, 2004; Rege and Telle,

⁵Note also that some papers have investigated the channels through which information disclosure leads firms to reduce emissions. Konar and Cohen (1997) identify that a stock price decline due to information disclosure leads firms to subsequently change their environmental behavior. The impact of such disclosure on firms’ financial performance has been analyzed in other papers (see e.g., Capelle-Blancard and Laguna, 2010; Gonenc and Scholtens, 2017).

2004; Soetevent, 2005; Samek and Sheremeta, 2014). Samek and Sheremeta (2014) note that the shame from being a low contributor is a more powerful motivation for giving than the prestige of being recognized as a high contributor. Although some studies have investigated how players behave in a public bad setting, that is, when the probability or size of a collective event (a loss) is affected by the group's decisions (e.g., Keser and Montmarquette, 2008; Blanco et al., 2016, 2017; Boun My and Ouvrard, 2019; Flambard et al., 2020), none of them, to our knowledge, has introduced name and shame devices in a public bad setting. Disclosure of low contributors should also play an important role in the avoidance of a collective loss.

Finally, this chapter is related to the law and economics literature on liability which has been quite extensively analyzed theoretically (Calabresi, 1970; Brown, 1973; Shavell, 1980) and has been identified as a means of reducing pollution (Kornhauser and Revesz, 1989, 1990; Endres and Bertram, 2006; Endres et al., 2008). Still from a theoretical perspective, some papers on liability have also investigated how this legal framework interacts with moral concerns in providing incentives to manage risky activities (Deffains and Fluet, 2013; Buchens et al., 2019). However, from an empirical perspective, no comparison of liability rules has been made on field data, and few experiments have been performed. Exceptions are Kornhauser and Schotter (1990, 1992), who test, in a single-actor (unilateral) and double-actor (bilateral) accident framework, the effects of strict liability and negligence on the reduction of a risk of unilateral accident and a risk of bilateral accident respectively. Angelova et al. (2014) also compare strict liability and negligence in terms of efficiency in reducing the probability of an accident. Using two precaution levels (care vs. no care), they find that both liability rules provide socially efficient incentives, but that roughly half of the subjects also invest in care under a "No Law" setting, where subjects cannot be sanctioned for not contributing. Finally, Deffains et al. (2019) compare a "No Law" setting with the two liability rules (strict liability vs. negligence) and implement two legal obligation enforcement levels (mild vs. severe).⁶ They show that individuals trade private benefits, net of legal liability, off for the net uncompensated losses caused to others. Finally, on the liability side, the closest paper to ours is Jacob et al. (2022) who experimentally compare the efficiency of two liability rules, namely joint and several liability and several (only) liability, in terms of incentives for (potentially insolvent) subjects to make investments to reduce the size of a damage

⁶Under severe law, subjects always have to compensate perfectly for any harm caused to others, i.e., the probability of detection is assumed to be 100%. Under mild law, the probability of detection is 50% only.

which occurs with certainty. Our experiment differs from theirs in several respects. First, and most importantly, information disclosure is not taken into account in their paper which focuses on liability rules only. Second, we adopt a public bad setting, which seems relevant to consider more than two subjects interacting with each other in order to reduce a common damage. Third, we consider that investments reduce the probability (and not the size) of harm, thus referring to other types of environmental harms.

The chapter is organized as follows. In Section 1.2, we display the experimental design and a simple theoretical model that allows us to derive predictions. Section 1.3 presents the results from our experiment, and Section 1.4 concludes and discusses the potential implications of this research.

1.2 Experimental design and predictions

1.2.1 Design

The experiment consists of a repeated game played by groups of four subjects for 20 periods. Following Andreoni and Petrie (2004), the composition of each group is randomly changed every five periods.⁷ While a repeated game moves us away from our (static) theoretical model of Subsection 1.2.2, it gives us the opportunity to observe group dynamics and learning within 5 given periods (see Andreoni (1988) and a plethora of follow-up studies). At the beginning of the experiment, each subject is endowed with 200 ECUs so that any group member is able to fully compensate for a potential loss of the same amount. In addition, at the start of each period, subjects receive an endowment of 19 ECUs and have to decide, simultaneously and without the possibility of communicating with the other group members, how many of those ECUs they are willing to invest in order to reduce the probability of a loss of 200 ECUs affecting their group. Note that this loss will be shared between the members depending on the rule in place, as explained below. The probability of occurrence of this loss diminishes as the contributions of the four group members increase, and is given by the following function:

$$p(x_i, x_j, x_k, x_l) = \frac{1}{1 + \alpha(x_i + x_j + x_k + x_l)} \quad (1.1)$$

⁷In Andreoni and Petrie (2004), the composition of the groups changes every 8 periods, for a total of 40 periods.

where x_i, x_j, x_k, x_l are the individual contributions to decreasing the probability, $i = 1, 2, 3, 4$, $j = 1, 2, 3, 4$, $k = 1, 2, 3, 4$, $l = 1, 2, 3, 4$, $i \neq j \neq k \neq l$ denoting the four subjects, and α is set at 0.19.⁸ If none of the four subjects contributes, the probability is 1 and the loss occurs with certainty. On the contrary, if all four subjects contribute their entire endowment (19 ECUs), the probability falls to zero and no harm can occur. In order to facilitate the subjects' decision making, a table displaying the probability for every possible contribution is presented in the instructions.⁹ The experiment is completely decontextualized so that only neutral terms such as gain, loss or contribution are used.

We consider four different treatments (see Table 1.1). In the so-called Per Capita treatment (PC-A)¹⁰, the loss is shared equally between the members of the group. This means that if the loss occurs, each member has to bear 1/4 of the loss, that is, 50 ECUs.

In the Proportional treatment (PR-A), the share of the loss that each subject has to bear in case of an accident depends on their relative level of contribution (to reducing the probability of the loss occurring). More precisely, the share of the loss for a subject i , denoted γ_i , is given by the ratio of their deviation from the maximum contribution (19 ECUs) to the sum of the four members' deviations. That is:

$$\gamma_i(x_i, x_j, x_k, x_l) = \frac{19 - x_i}{4 * 19 - (x_i + x_j + x_k + x_l)} \quad (1.2)$$

If all subjects contribute the same amount to the reduction of probability, the individual share of loss simplifies to a per capita one. If a subject i decides not to contribute and if the three others contribute the maximum amount (19 ECUs), subject i bears the entire loss. If a subject i decides to contribute the maximum amount, their share of the loss is reduced to 0.

We implement the identification mechanism in the treatments PC-ID and PR-ID.¹¹ We replicate the two sharing rules and, in addition, subjects can be publicly identified for their contributions.

We follow Andreoni and Petrie (2004) and Samek and Sheremeta (2014) and use digital photos

⁸Increasing α leads both to a decrease in the level of the probability (for given contributions), and to a decrease in the marginal benefit from contributing. For α lower than 0.19, the theoretical equilibrium under the per capita rule (see later) is the corner solution, i.e., contributing 19. $\alpha = 0.19$ leads to an interior solution. Higher values of α lead to closer equilibrium values between the per capita and the proportional rules. This value of α is the one which provides both interior solutions and the highest difference in equilibrium values.

⁹To avoid the subjects needing mathematical skills in order to understand the function of probability, they were not given the functional form of that function but a table of all probabilities instead. See the instructions in Appendix 1.D.

¹⁰A stands for Anonymous.

¹¹ID stands for Information Disclosure.

Table 1.1: Experimental treatments

	Anonymous	Identification
PC	PC-A	PC-ID
PR	PR-A	PR-ID

and first names to identify individuals to one another.¹² In the instructions, subjects are told that at the end of the experiment, the picture and the first name of the five worst contributors, characterized by the lowest average contributions over four randomly selected periods, will be displayed on the computer screens of all participants. This random draw of four periods implies that a given subject may potentially be identified even in the absence of an accident. Indeed, information disclosure works on the basis of random audits which are totally independent of any damage caused or pollution emissions. It differs from legal inquiries which are conducted *ex post*, once the damage happened. The identification mechanism operates *ex ante*, irrespective of the occurrence of damages and allows us to avoid path dependence. If a subject were possibly identified only in case of an accident, then a subject making a low investment only once might be identified and a subject making zero investment except once might not be. This also makes over-investment in the periods following an accident less likely. Finally, since our goal is to work on the subjects' sensitivity to social pressures (or stigmatization), we show the picture and the name of the five subjects who contribute the least among all the participants of the session whether or not they have been in the same group.

In each treatment, subjects make the same decision, that is, choosing how much they want to contribute to decreasing the probability of a loss. In addition, they are also requested in every period (in addition to the contribution decisions) to indicate their beliefs about the average contribution of the three other members of their group. They are rewarded according to the accuracy of their beliefs.¹³ Their gains for each period depend on the occurrence of the loss. If there is no loss, subjects obtain their endowment of 19 ECUs minus their investment in reducing the probability. In case of a loss, they get their endowment of 19 ECUs minus their investment in reducing the probability, minus their share of the loss which differs according to the liability

¹²As pointed out by Samek and Sheremeta (2014), photos capture and preserve the appearance of the person but do not allow for communication, which may confound the effects of identification alone. In addition to the photos, we therefore included first names.

¹³We follow Gächter and Renner (2010) for belief elicitation. Subjects earn 6 ECUs if they correctly (± 0.5 ECUs) predict the average contribution of the three other members and 3 ECUs divided by the (absolute) estimation error otherwise.

rule. At the end of each period, subjects are informed of the total contribution of their group, the resulting probability, the occurrence of the loss and their own payoffs.

In addition to the main game, we also elicit participants' risk attitude using the method developed by Eckel and Grossman (2002). Participants are presented with 5 different gambles and have to select only one of them. Each gamble offers a 50% chance of getting the low payoff and a 50% chance of getting the high payoff (see Appendix 1.D). Gamble 1 is a certain gamble (no risk) while Gamble 5 is the riskiest gamble (highest expected return but also highest standard deviation). Highly risk-averse subjects are expected to choose gambles with the lowest standard deviations.

1.2.2 Model and predictions

We build here a simple model, which is based on the design introduced above. The aim is to derive some predictions to be tested in the experiment.

We consider a group of four symmetric risk-neutral agents. We note W their initial endowment, and H the loss that they can cause altogether to a passive third party (e.g., the environment). x_i is the contribution that an agent i can make in order to reduce the probability of causing the loss H , with $i = 1, 2, 3, 4$. Any positive contribution is costly, through a decrease in the additional endowment $R(x_i)$ (with $\frac{\partial R(x_i)}{\partial x_i} < 0$).

Recall that (strict) liability always applies in case of a loss occurring: the group, as a whole, always pays for the entire loss that it causes to the passive third party. The loss is entirely repaired by the group, but how this payment is shared between the four agents of the group depends on the sharing rule r which applies ($r = PC, PR$). Note γ_i^r the share of the loss an agent i has to bear under a rule r . We have $\gamma_i^{PC} = \frac{1}{4}$ in case of a per capita rule, and $\gamma_i^{PR} = \gamma_i(x_i, x_j, x_k, x_l)$, as defined by (1.2), in case of a proportional rule. As a result, the agent i 's expected payoff depending on the sharing rule r is:

$$E[\Pi_i^r(x_i)] = W + R(x_i) - \gamma_i^r p(x_i, x_j, x_k, x_l) H$$

with $i = 1, 2, 3, 4$, $j = 1, 2, 3, 4$, $k = 1, 2, 3, 4$, $l = 1, 2, 3, 4$, $i \neq j \neq k \neq l$.

Moreover, we suppose that each agent may receive an additional benefit from (or may incur an additional cost from) Society. Here, Society refers to any party who can observe and make a value

judgment on the actions made by an agent: it can be other group members, or even an external party who only observes any public information which is disclosed. The benefit, or the cost, that an agent may receive from Society relates to others' perception of the agent's ability to be concerned about the consequences of their action (through their contribution in causing a loss). For an agent who is an individual, it refers to social (dis)esteem from others.¹⁴ In accordance with our experimental design, which fits with decisions made by individuals or SME (Small and Medium-sized Enterprises), we will talk about social esteem.¹⁵ We note the social (dis)esteem as e , and the agent's sensitivity to (dis)esteem β_i (with $\beta_i > 0$). As a result, an agent i utility is :

$$u_i = E[\Pi_i^r(x_i)] + \lambda\beta_i e \quad (1.3)$$

e can be seen as a coefficient of others' (dis)esteem: $e > 0$ means others have esteem towards agent i , $e < 0$ means disesteem. The higher the absolute value of e , the stronger the (dis)esteem.¹⁶ λ is a dummy variable: $\lambda = 0$ means the agent i is a *homo oeconomicus*, who is insensitive to (dis)esteem, and $\lambda = 1$ means the agent i is a *homo behavioris*, who is sensitive to (dis)esteem.

Depending on the sharing rule r and the value of λ , we return to the four treatments defined above in Table 1.1 and we can now provide a theoretical basis for them. Given our specifications, we can complete Table 1.1 as follows:

¹⁴The model could fit with monetary gains/losses, due to a variation in the firm's brand image or reputation. However, our experimental design do not include the possibility for pecuniary losses other than those due to liability in case of a loss occurring.

¹⁵Many SME are managed by owner-managers who have at least a personal responsibility on decisions they make for their company. They are personally identified, and are personally impacted by what happens to their company. Decisions are thus close to those which are made for an individual purpose. As an illustration, Afsah et al., 1996 show that firms are sensitive to the opinion of local communities. We can note that SME, like larger firms, may also be subject to reputational monetary gains or losses, which are not captured by our experiment. As a consequence, the impact of this additional benefit/cost on SME could be higher than the one we measure in this experiment.

¹⁶As in Deffains and Fluét (2013), (dis)esteem holds through the others' view of the agent's ability to care about, and to contribute to reducing the expected common loss. This agent's concern towards the loss could be included in the model, through an additional cost in (1.3) such as: $-p(x_i)\theta H$, with θ the degree of the agent's concern for the loss (with $\theta \geq 0$). (Dis)esteem is based on the underlying rationale that others cannot observe θ , but they try to infer its value, especially through the information disclosed by the identification mechanism. Esteem (resp. disesteem) thus plays a role when others think that we have a high (resp. low) value of θ . Hence, θ is only an instrumental variable, that we choose not to introduce to ease the exposition.

Table 1.2: Experimental treatments and parameters

	Anonymous	Identification
PC	PC-A	PC-ID
	$\gamma_i^{PC} = 1/4$ $\lambda = 0$	$\gamma_i^{PC} = 1/4$ $\lambda \in \{0, 1\}$
PR	PR-A	PR-ID
	γ_i^{PR} $\lambda = 0$	γ_i^{PR} $\lambda \in \{0, 1\}$

1.2.2.1 Per capita sharing rule (PC), when agents are *homo oeconomicus* ($\lambda = 0$)

Perfect symmetry between agents implies equal contributions in equilibrium. Below, we introduce the best response of a given agent i , to the contributions of the three other agents. The utility of an agent i , who is a *homo oeconomicus* under a per capita rule is:

$$u_i = E[\Pi_i^{PC}(x_i)] = W + R(x_i) - \frac{1}{4}p(x_i, x_j, x_k, x_l)H \quad (1.4)$$

The equilibrium value $x_i^{PC}(x_j, x_k, x_l) = x_i^{PC}$ thus satisfies:

$$\frac{\partial E[\Pi_i^{PC}(x_i)]}{\partial x_i} = 0 \Leftrightarrow -\frac{\partial p(x_i, x_j, x_k, x_l)}{\partial x_i} \frac{H}{4} = -\frac{\partial R(x_i)}{\partial x_i} \quad (1.5)$$

We now turn to the private decision-making of a *homo oeconomicus* under a proportional rule.

1.2.2.2 Proportional sharing rule (PR), when agents are *homo oeconomicus* ($\lambda = 0$)

Again, perfect symmetry implies equal contributions at equilibrium. The utility of an agent i is:

$$u_i = E[\Pi_i^{PR}(x_i)] = W + R(x_i) - \gamma_i(x_i, x_j, x_k, x_l)p(x_i, x_j, x_k, x_l)H \quad (1.6)$$

The equilibrium value $x_i^{PR}(x_j, x_k, x_l) = x_i^{PR}$ satisfies:

$$\begin{aligned} \frac{\partial E[\Pi_i^{PR}(x_i)]}{\partial x_i} &= 0 \\ \Leftrightarrow - \left[\frac{\partial \gamma_i(x_i, x_j, x_k, x_l)}{\partial x_i} \cdot p(x_i, x_j, x_k, x_l) + \frac{\partial p(x_i, x_j, x_k, x_l)}{\partial x_i} \cdot \gamma_i(x_i, x_j, x_k, x_l) \right] H &= -\frac{\partial R(x_i)}{\partial x_i} \end{aligned} \quad (1.7)$$

1.2.2.3 *Homo oeconomicus* ($\lambda = 0$): comparison of sharing rules

We compare incentives to contribute between the two sharing rules, *PC* and *PR*, for a *homo oeconomicus* agent ($\lambda = 0$). When comparing (1.7) with (1.5), we can see that both marginal costs of contributing are equal, but the marginal benefits are different. In Appendix 1.A, we show that for a level of contribution which is equal to the equilibrium contribution under the PC rule (i.e., $x_i = x_i^{PC}$), the marginal benefit of contributing is higher under the PR rule than under the PC rule. This is due to a double marginal benefit of contributing under the PR rule, which allows for the reduction of both the probability of an accident and the share of the cost to be paid (all other things being equal). Given the choice of the functions and the values of the parameters, the equilibrium investments that solve (1.5) and (1.7) are respectively 2.74 and 4.84. This leads to the following prediction.

Prediction 1 *In a symmetric setting, the proportional sharing rule leads to higher contributions than the per capita rule, when agents are not sensitive to (dis)esteem from others ($\lambda = 0$).*

In the three next subsections, we study whether (and to what extent) contributions differ when agents are sensitive to (dis)esteem from others.

1.2.2.4 Per capita sharing rule (PC), when agents are *homo behavioris* ($\lambda = 1$)

The fact of being identified as a low contributor provides Society with information. From this information, Society infers the extent to which the identified agent cares about the consequences of their actions.

The utility of an agent i , who is sensitive to (dis)esteem, under a per capita rule is given by (1.3) with $r = PC$. Before the disclosure of any information via the identification mechanism, others have a prior esteem which is denoted by \bar{e} . In the case where the agent is identified as a low contributor, this prior is updated to become e_B^r , with $e_B^r < \bar{e}$, given the rule r . Where the agent is not identified as a low contributor, this prior is updated to become e_G^r , with $e_G^r > \bar{e}$. Denoting by $q^r(x_i, x_j, x_k, x_l)$ the probability of being identified as a low contributor, given a contribution x_i and contributions x_j, x_k, x_l of the others, and a rule r (with $\frac{\partial q^r(x_i, x_j, x_k, x_l)}{\partial x_i} < 0$), the *ex ante*

utility for an agent being sensitive to (dis)esteem under a per capita rule is:

$$\begin{aligned} u_i &= E[\Pi_i^{PC}(x_i)] + \beta_i [q^{PC}(x_i, x_j, x_k, x_l)e_B^{PC} + (1 - q^{PC}(x_i, x_j, x_k, x_l))e_G^{PC}] \\ \Rightarrow u_i &= E[\Pi_i^{PC}(x_i)] + \beta_i [e_G^{PC} - q^{PC}(x_i, x_j, x_k, x_l)\Delta^{PC}] \end{aligned} \quad (1.8)$$

with $\Delta^{PC} = e_G^{PC} - e_B^{PC}$

1.2.2.5 Proportional sharing rule (PR), when agents are *homo behavioris* ($\lambda = 1$)

When a proportional sharing rule is enforced, the *ex ante* utility of an *homo behavioris* agent i is:

$$\begin{aligned} u_i &= E[\Pi_i^{PR}(x_i)] + \beta_i [q^{PR}(x_i, x_j, x_k, x_l)e_B^{PR} + (1 - q^{PR}(x_i, x_j, x_k, x_l))e_G^{PR}] \\ \Rightarrow u_i &= E[\Pi_i^{PR}(x_i)] + \beta_i [e_G^{PR} - q^{PR}(x_i, x_j, x_k, x_l)\Delta^{PR}] \end{aligned} \quad (1.9)$$

with $\Delta^{PR} = e_G^{PR} - e_B^{PR}$

When we compare (1.4) with (1.8), and (1.6) with (1.9), we can deduce that the sensitivity to (dis)esteem provides additional incentives to contribute since, whatever the sharing rule, an increase in the level of contribution increases the probability of not being identified as a low contributor, and thus benefiting from a favorable update (or avoiding a detrimental update) of others' esteem (i.e., $\frac{\partial [e_G^{PR} - q^{PR}(x_i, x_j, x_k, x_l)\Delta^{PR}]}{\partial x_i} > 0$). The following prediction can be made.

Prediction 2 *The identification mechanism should raise the contribution levels chosen by each player, whatever the liability sharing rule: the contribution levels should thus be higher under PC-ID (resp. PR-ID) than under PC-A (resp. PR-A).*

1.2.2.6 *Homo behavioris* ($\lambda = 1$): comparison of sharing rules

The ID mechanism provides additional incentives to contribute, for a given rule. However, the incentives provided by this mechanism are different between rules.

Recall that (dis)esteem, expressed by Society, is the opinion (or belief) that others have towards oneself, in general or as regards a given personal quality. In our analysis, (dis)esteem holds on the agent's ability to care about, and to contribute to reducing the expected common loss. However,

the informational content of being recognized as a low contributor, or not, is different depending on which sharing rule applies.

In case of a proportional sharing rule, a decrease in the agent's contribution leads to an increase in their share of liability (and a decrease in the others' shares). As a consequence, the negative externality which follows from lowering their contribution (via the increase in the probability of causing the common loss) is somewhat mitigated by the increase in their share in the payment of the loss: the low contribution is 'punished' by a higher share of liability, in a rationale close to a polluter-pays principle. The agent thus takes responsibility for their (detrimental) action. This rationale does not work under a per capita rule, which leaves room for more free-riding: the negative externality which comes from a low contribution is not balanced by a higher participation in the payment of the loss. A given decrease in contribution x_i thus leads to a higher increase in the expected loss for the other group members. Finally, because the proportional rule provides higher pecuniary incentives to contribute than the per capita rule, not being recognized as a low contributor under proportional may provide less merit than under per capita.

As a consequence of all these effects, under the PC rule, being identified as a low contributor provides a clear signal of being little concerned by the consequences of the loss, while the signal is more 'blurred' under the PR rule since a low contributor pays for a larger share of the loss. It follows that: $\Delta^{PR} < \Delta^{PC}$. Then, for similar probabilities of being identified as a low contributor between the sharing rules (i.e., $q^{PC}(x_i, x_j, x_k, x_l) = q^{PR}(x_i, x_j, x_k, x_l)$), we obtain the following prediction.

Prediction 3 *Incentives to contribute provided by the identification mechanism should be higher under a per capita rule than under a proportional rule.*

1.3 Results

1.3.1 Procedure

A total of 240 subjects participated in 12 sessions (3 sessions per treatment) in October 2019 and in March 2020 at the Laboratory of Experimental Economics of Strasbourg (LEES). The subjects were recruited from a list of experimental subjects maintained at the LEES using the ORSEE software (Greiner, 2015). The experiment was computerized. Upon arrival, each subject

was randomly assigned to a computer. The instructions were read aloud by the experimenter and, before starting, a comprehension questionnaire was administered to check that the rules were well understood. All questions were answered privately. Then the main game took place, followed by the elicitation of risk preferences and finally a post-experimental questionnaire (see Appendix 1.D). At the end of the experiment, one period from the main game was drawn randomly for actual payment. A random draw was also made to pick the payoff earned by subjects in the risk elicitation task. The conversion rate was 20 ECUs to 1.5 € for the main game and 4 ECUs to 1 € for the risk aversion elicitation task. Subjects were paid their earnings in a separate room and privately at the end of the session. Average earnings were 19.95 € (std. dev. = 3.04). The experiment lasted 60 minutes on average.

In the treatments PC-ID and PR-ID, we display digital photos of low contributors. Upon arriving in the lab, a digital photograph of each participant was taken by the experimenter. Subjects gave their consent to the use of the picture during the experiment and they were told that all pictures would be deleted at the end of the experiment. They were free to stay to attend the deletion. At the beginning of the experiment, participants also had to enter their first name on the screen so that it could be associated with their picture.

In the following subsections, we present the results in two steps. First, we look at the average contributions to decreasing the probability of a loss and perform a series of non parametric tests. Second, we examine the individual choices of contributing in order to identify the effects of the treatments on subjects' behavior.

1.3.2 Average contributions

Table 1.3 presents the average contributions (and standard deviations) as well as the proportions of minimum (0 ECU) and maximum (19 ECUs) contributions in each treatment. On average, contributions are higher in the Proportional treatments than in the Per Capita treatments (PR-A and PR-ID compared respectively with PC-A and PC-ID). Among the four treatments, subjects contribute the most in PR-ID. When anonymity is fully preserved in the Proportional treatment (PR-A), average contributions are lower but still higher than in the Per Capita treatment (PC-A) that displays the lowest level of contributions. In both Proportional and Per Capita treatments, when information disclosure is introduced, average contributions increase.

We first test for the effect of the liability rule and look at the differences between PC-A and PR-A

Table 1.3: Mean, minimum and maximum contributions per treatment (std. dev. in parentheses)

Treatment	Average contribution	% of contributions = 0	% of contributions = endowment
PC-A	7.27 (4.24)	7.75% (26.75)	4% (19.60)
PC-ID	9.03 (5.62)	7.25% (25.94)	13.33% (34.01)
PR-A	9.91 (5.10)	3.92% (19.41)	9.58% (29.45)
PR-ID	11.30 (5.25)	2% (14.01)	16.33% (36.98)

wherein subjects are fully anonymous.¹⁷ The way of apportioning liability appears to affect the contribution levels since the average contribution rises from 7.27 in PC-A to 9.91 in PR-A and this increase is significantly different from zero ($p = 0.0003$). It also significantly increases the proportion of maximum contributions from 4% in PC-A to 9.58% in PR-A (test of proportion, $p = 0.0000$) and decreases the percentage of minimum contributions from 7.75% in PC-A to 3.92% in PR-A (test of proportion, $p = 0.0001$).

The same conclusion applies when contributors can be identified. Here, the average contribution increases from 9.03 in PC-ID to 11.30 in PR-ID ($p = 0.0089$) and the percentage of maximum contributions goes up from 13.33% in the PC-ID treatment to 16.33% in the PR-ID treatment. This rise is significant (test of proportion, $p = 0.0387$), albeit to a lesser extent than in the treatments where contributors cannot be identified. It seems that the impact of the liability rule is mitigated by the effect of identification. The percentage of minimum contributions falls from 7.25% in PC-ID to 2% in PR-ID (test of proportion, $p = 0.0000$).

In addition to looking at the percentages of maximum and minimum contributions, we can compare the distributions of contributions¹⁸ and determine whether the proportional rule modifies the shape of the distributions. In both cases either with and without anonymity, a Kolmogorov-Smirnov test allows us to reject the null hypothesis of equality of distributions. There is a significant difference between the PC-A and PR-A treatments ($p = 0.001$), as well as between the PC-ID and PR-ID treatments ($p = 0.009$).

This supports *Prediction 1* according to which the proportional sharing rule leads to higher investments than the per capita rule.

¹⁷Unless specifically noted, we report the significance levels of a two-sided Mann-Whitney (MW) rank-sum test taking individual averages as the unit of observation. Given the sample size of 60 subjects per treatment and the averages and standard deviations presented in Table 1.3, we must acknowledge that the statistical power of two-sample comparisons can be low and is around 57% depending on the test.

¹⁸See Appendix 1.B for the distributions of contributions per treatment.

Result 1: Contributions to reduce the probability of a damage are higher under a proportional rule of liability than under a per capita rule.

In order to identify the effect of identification, we now compare treatments for a given liability rule. That is, we look at the differences between PC-A and PC-ID and between PR-A and PR-ID. In the Per Capita treatments, when contributors can be identified, it significantly increases the average level of contributions. As shown in Table 1.3, the average contribution goes from 7.27 in PC-A to 9.03 in PC-ID ($p = 0.0384$). In the Proportional treatments, allowing for the identification of the worst contributors has a positive impact on the average level of contributions too. The average contribution increases from 9.91 in PR-A to 11.30 in PR-ID but the difference is not statistically significant ($p = 0.1076$). This finding is consistent with *Prediction 2* regarding the PC rule, but contradicts the prediction regarding the PR rule. As a consequence, *Prediction 3* is found to be valid, since we find a positive effect of the ID mechanism under a PC rule and no effect of that mechanism under a PR rule. This result can be explained by the fact that when a proportional rule applies, low contributors bear a greater share of liability than high contributors. Therefore, the externality they impose on others is less important than when a per capita rule applies. The disesteem from others is lower in a proportional treatment since contributors assume their small contributions by paying a higher part of the loss.

Regarding the proportions of maximum contributions, we find that identification significantly increases these proportions in the Per Capita treatments and in the Proportional treatments. The percentage of maximum contributions goes from 4% in PC-A to 13.33% in PC-ID (test of proportion, $p = 0.0000$) and it increases from 9.58% in PR-A to 16.33% in PR-ID (test of proportion, $p = 0.0000$). Interestingly, when we look at the proportions of minimum contributions, we do not find a significant difference between PC-A and PC-ID (test of proportion, $p = 0.6419$). However, the percentage of free-riding significantly decreases from 3.92% in PR-A to 2% in PR-ID (test of proportion, $p = 0.0056$). When we perform a Kolmogorov-Smirnov test, we find a significant difference between the total distributions of PC-A and PC-ID and no difference between those of PR-A and PR-ID. Thus, identification modifies the distribution in the Per Capita treatments (Kolmogorov-Smirnov test, $p = 0.016$) while it does not in the Proportional treatments (Kolmogorov-Smirnov test, $p = 0.378$).

Result 2: Recognizing the lowest contributors significantly increases contributions under a per capita rule of liability but does not increase contributions under a proportional rule.

Figure 1.1 illustrates the average contributions per period in each of the four treatments. The declining trend we observe is a stylized fact that is consistent with multiple rounds public goods games where contributions tend to decline as the game is repeated (Andreoni and Petrie, 2004). It is also clear from Figure 1.1 that PC-A is the least efficient treatment in terms of maintaining high contributions while PR-ID seems to be the most efficient one. Also, in PR-ID, the decay of contributions is considerably reduced compared to other treatments. Interestingly, the curves for PC-ID and PR-A are rather close and there is no significant difference in average contributions between these two treatments ($p = 0.2635$). This would suggest that it is equally effective, all else being equal, to implement a procedure of identification of low contributors with a per capita rule or to use a proportional rule alone. This result is interesting, especially for public policy. When it is difficult to identify the precise degree of liability of a firm (or when the legal framework does not allow the use of proportionality), a per capita rule where only the worst contributors need to be identified publicly, might prove to be as efficient a solution as a proportional rule. We will discuss this result further in the conclusion.

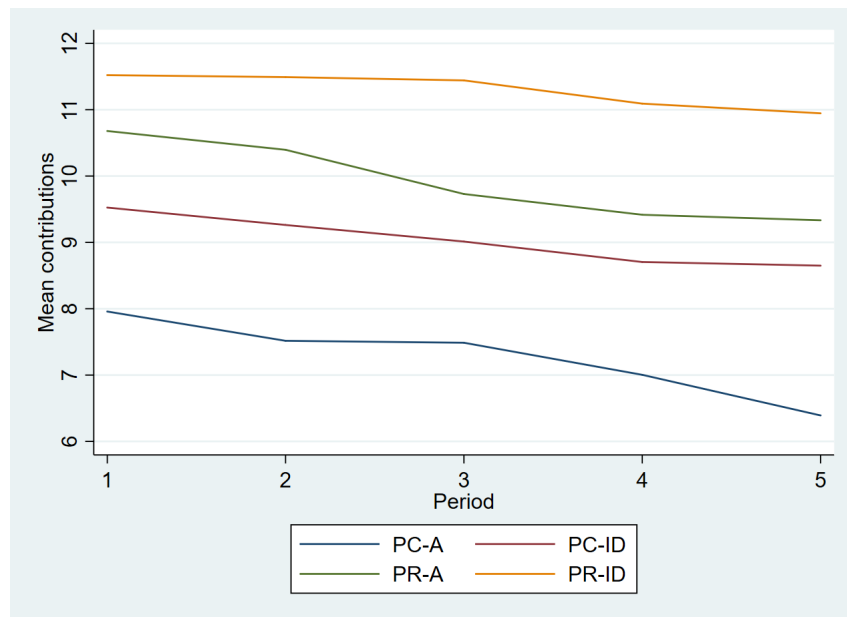
Result 3: A per capita rule combined with an identification mechanism makes it possible to reach the same level of contribution as a proportional rule alone.

Figure 1.1 also shows an increase in contributions in the 6th, 11th, and 16th periods. These surges correspond to the reallocation of groups and display a restart effect. To get rid of these reallocation effects, Figure 1.2 shows the mean contributions combining the four five-round sequences per treatment. The declining tendency seems to be more pronounced in the treatments without identification. In PC-A, the mean contribution starts at 7.96 and ends at 6.39 and in PR-A, it goes from 10.68 to 9.33. The level of mean contributions looks more stable when anonymity is broken. In PC-ID, the mean contribution begins at 9.53 and decreases to 8.65. The effect of repetition seems even less important in PR-ID (11.52 to 10.95). This means that the threat of being

Figure 1.1: Average contributions over time per treatment



Figure 1.2: Average contributions combining all 5-period sequences



exposed might prevent contributions from declining over time as much as when liability applies alone. The comparisons of the treatments with and without anonymity indicate that there is a significant difference between PC-A and PC-ID ($p = 0.0372$) and between PC-A and PR-ID ($p = 0.0669$).¹⁹ However, the difference between PR-A and PR-ID is not statistically significant ($p = 0.1657$) nor is it between PC-ID and PR-A ($p = 0.1050$).

¹⁹The p-values of MW tests are based on the difference between the average contribution of the four first periods in each group and the average contribution of the four last periods in each group by individuals.

Result 4: The identification of low contributors reduces the decay of contributions compared to situations in which anonymity is guaranteed.

1.3.3 Individual decisions

We now turn to the analysis of individual contributions in order to explain the differences between treatments. We first estimate a Tobit model with random effects since our dependent variable (the level of contribution) is left-censored at 0 and right-censored at 19.²⁰ Table 1.4 presents the different variables that are used in the regressions and the results are displayed in Table 1.5. In specification (1), the analysis is based on the pooled data over the four treatments. We identify the treatment effects by using three dummy variables (the baseline being PC-A). In specifications (2) and (3), we focus on the Per Capita treatments and the Proportional treatments separately in order to isolate the effect of identification. In the last two columns, we estimate logit models to identify the drivers of choice to contribute nothing and to contribute the total endowment.

We see from column (1) in Table 1.5 that all the coefficients of the treatment variables are positive and statistically significant. The contributions are higher in PC-ID, PR-A and PR-ID than in PC-A, but the highest difference in magnitude is found for PR-ID which is the most efficient treatment to increase contributions. A Wald test of equality of the coefficients of PC-ID and PR-ID indicates that they are significantly different ($p = 0.022$). However, there is no significant difference between the coefficients of PR-A and PR-ID ($p = 0.118$) nor between those of PC-ID and PR-A ($p = 0.474$). This furthermore supports *Results 1, 2 and 3* obtained with the non-parametric tests.

Among other results, the occurrence of a loss in the previous period increases the contributions. This can be explained by the availability heuristic (Kahneman and Tversky, 1973). Subjects recall the loss in the previous period perfectly and, therefore, tend to overstate the probability of a loss in the current period. It also supports the reinforcement effect for losses attributed to Thaler and Johnson (1990). It means that decision makers will act more cautiously after experiencing losses. In our case, subjects invest more in reducing the probability of a loss if it happened in

²⁰All results are robust to the use of other specifications such as OLS or individual clustered standard errors and whether or not socio-demographic variables are included.

Table 1.4: Variables definition

Variables	Definition	Mean (std. dev.)
PC-ID	1 if the treatment is PC-ID; 0 otherwise	0.25 (0.43)
PR-A	1 if the treatment is PR-A; 0 otherwise	0.25 (0.43)
PR-ID	1 if the treatment is PR-ID; 0 otherwise	0.25 (0.43)
Loss _{<i>p</i>-1}	1 if a loss occurred in the previous period; 0 otherwise	0.14 (0.34)
AveragePartners _{<i>p</i>-1}	Average contribution of the 3 other group members in the previous period	9.43 (3.82)
Period	1 in period 1, 2 in period 2, ..., 20 in period 20	10.50 (5.77)
Socio-demographic variables		
Gamble	1 if subject chooses Gamble 1, ..., 5 if subject chooses Gamble 5	3.47 (1.35)
Risk-seeking	Answer from an 11-point Likert scale: 0 standing for a careful person and 10 for a person who loves taking risks	5.37 (2.09)
Female	1 if subject is female; 0 otherwise	0.5 (0.5)
Age	Age of subject	21.40 (2.66)
Econ-manag	1 if subject studies economics and management; 0 otherwise	0.54 (0.5)
Distrust	1 if subject states that “We must be very careful with people”; 0 otherwise	0.73 (0.45)
Earnings	1 if subject states that “They only cared about their own payoff during the game”; 0 otherwise	0.45 (0.5)

the previous period. While empirical results are mixed, Nielsen (2019) also finds support for the reinforcement effect. The effect of the average contribution of the other group members in the previous period²¹ is positive and highly significant. This means that the higher the average contribution of the other group members in the previous period, the more subjects are willing to contribute. The coefficient of *Period* is negative which indicates that contributions decrease over time and has been observed in Figure 1.1. In column (1) of Table 1.A in Appendix 1.C, we also present a regression in which we introduce a dummy variable for each period of group reallocation (i.e., the 6th, 11th and 16th periods) and we find significant and positive reallocation effects suggesting some restart effects.

²¹We used this lagged variable rather than the subject’s belief about the average contribution of the other group members since we obtain the same results no matter which variable is employed but the effects are more statistically significant with the former.

Table 1.5: Tobit and logit estimations

	All	PC	PR	Free-riding	Full contrib.
	(1)	(2)	(3)	(4)	(5)
PC-ID	2.001** (1.012)	2.073** (0.939)		-.022 (0.024)	0.048** (0.022)
PR-A	2.727*** (1.015)			-.032 (0.023)	0.045** (0.022)
PR-ID	4.313*** (1.021)		1.695* (1.024)	-.051** (0.022)	0.061** (0.024)
Loss _{p-1}	0.512*** (0.131)	0.598*** (0.161)	0.417** (0.208)	-.012* (0.007)	0.014* (0.007)
AveragePartners _{p-1}	0.277*** (0.02)	0.31*** (0.026)	0.244*** (0.03)	-.000 (0.001)	0.003*** (0.001)
Period	-.071*** (0.008)	-.077*** (0.01)	-.064*** (0.013)	0.002*** (0.000)	0.001 (0.000)
Gamble	-.369 (0.288)	-.255 (0.369)	-.254 (0.427)	0.017*** (0.006)	-.008 (0.007)
Risk-seeking	-.451** (0.187)	-.327 (0.243)	-.712*** (0.276)	0.002 (0.004)	-.011*** (0.004)
Female	-2.238*** (0.779)	-1.452 (0.984)	-2.639** (1.147)	-.005 (0.016)	-.084*** (0.015)
Age	0.13 (0.145)	0.064 (0.179)	0.137 (0.222)	0.005** (0.003)	0.007** (0.003)
Econ-manag	-.962 (0.782)	-2.907*** (0.998)	1.058 (1.137)	0.015 (0.016)	-.018 (0.019)
Distrust	0.887 (0.809)	2.307** (1.079)	-.767 (1.132)	-.02 (0.016)	0.004 (0.019)
Earnings	-.449 (0.731)	-2.589*** (0.979)	1.728* (1.021)	0.051*** (0.016)	0.022 (0.017)
Constant	7.613** (3.757)	8.142* (4.520)	10.668* (5.873)		
Obs.	4560	2280	2280	4560	4560
Left-censored obs.	245	177	68	/	/
Right-censored obs.	487	194	293	/	/

Estimated standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Average marginal effects are reported in models (4) and (5).

In column (2) of Table 1.5, we focus solely on the Per Capita treatments to get rid of the effect of the liability rules. The effect of identification appears to be statistically significant ($p = 0.027$) which means that when anonymity is broken in the Per Capita treatments, contributions are higher on average than when it is preserved. Like in regression (1), the occurrence of a loss and higher contributions from the other group members in the previous period increase the individual contributions. The coefficient of *Period* is negative and highly significant. However, while Figure 1.2 seemed to indicate that identification prevented contributions from declining over time as much as when anonymity was preserved, we do not find econometric evidence of this trend. Indeed, in regression (2) of Table 1.A in Appendix 1.C, we introduce an interaction variable of *Period* and *PC-ID* and it appears not to be statistically significant. This contradicts *Result 4* based on the non parametric tests. Regarding the socio-economic variables, we find that subjects who study economics and management contribute less when facing per-capita incentives. It is likely that they have covered this topic in class, so that they might be aware that their optimal strategy is to deviate. Also when subjects are wary of people, they tend to contribute more. They may expect low contributions from the other group members so they invest more to compensate for that. In these treatments, subjects have an incentive to free-ride in order to maximize their payoff. This could explain the negative and significant coefficient of *Earnings*.

Regression (3) of Table 1.5 focuses on the Proportional treatments only. As expected from the non parametric tests, the identification of low contributors does not affect the level of contributions, as evidenced by the coefficient of *PR-ID* which is not statistically significant ($p = 0.098$). The effects of the occurrence of a loss, the contributions of others and time are the same as in the previous regressions. Breaking anonymity still has no effect on the decline of contributions over time as shown by the coefficient of the interaction variable of *Period* and *PR-ID* which is not statistically significant.²² It is still not in line with *Result 4* derived from the non parametric tests. If we look at the socio-economic variables, we observe that subjects who self-identify themselves as risk-seeking persons contribute less. By doing so, they increase both the probability of incurring a loss and their share of liability. There is a gender effect as shown by the negative and significant coefficient of *Female*. It seems that women tend to contribute less on average, which is consistent with Brown-Kruse and Hummels (1993) who show that males tend to contribute more than females in public goods games.

²²See column (3) of Table 1.A in Appendix 1.C.

In the last two columns, we estimate a random-effect Logit model to explain the decision to contribute zero ECU or to contribute the total amount of the endowment. In regression (4), the dependent variable equals one when subjects contributed 0 ECU to decreasing the probability and zero otherwise. In regression (5), the dependent variable is equal to one if subjects contributed their 19 ECUs and zero otherwise. Focusing first on regression (4), it turns out that PR-ID is the only treatment that makes free-riding less likely compared to PC-A. In other words, identification does not suffice to reduce the chances of free-riding when a per capita rule applies nor does the proportional rule when anonymity of contributors is preserved. However, a Wald test of equality of the coefficients of PR-A and PR-ID indicates that they are not significantly different ($p = 0.296$). That means that with a proportional rule, identifying low contributors does not reduce the probability of contributing nothing. The occurrence of a loss in the previous period diminishes the probability of free-riding, although the effect is marginally significant. Subjects may want to avoid incurring a loss again and they are therefore less willing to free-ride. The effect of time is positive as pointed out by the positive and significant coefficient of *Period*. This is in line with contributions declining over time. As time goes by, subjects may be tempted to contribute nothing to decrease the probability of a loss. The coefficient of *Gamble* is positive and highly significant, meaning that subjects who choose the riskiest gambles have more chances of free-riding. Subjects who try to maximize their earnings are also more likely to contribute nothing since it allows them to increase their own payoff by 19 ECUs if no loss occurs.

Finally, when looking at the probability of contributing 19 ECUs, we see that the coefficients of the three treatment variables are positive and significant which indicates that the probability is higher in all of these treatments than in PC-A. Nevertheless, the coefficients of PR-A and PR-ID are not statistically different as evidenced by the Wald test of equality of the coefficients ($p = 0.560$). Therefore, when a proportional rule applies, breaking anonymity has no effect on the likelihood of contributing the total endowment. The occurrence of a loss in the previous period affects the probability of contributing 19 ECUs positively, although this effect is only marginally significant. Subjects refer to past decisions of the other group members to make their own. If the other members contribute more in the previous period then it is more likely that subjects will contribute the maximum amount of ECUs in the current period. Subjects who state that they love taking risks show less likelihood of contributing 19 ECUs. There is a strong gender effect which tells us that women are less likely to contribute their entire endowment. This could

explain the gender effect we found in model (3) of Table 1.5.

Result 5: Recognizing the lowest contributors increases the proportion of full contributions when a per capita rule applies.

1.4 Discussion and conclusion

In this chapter, we run an experiment to analyze the impact of information disclosure on incentives to prevent a damage when several contributors can be held liable if it occurs. Agents decide on their contributions to reduce the probability of harm; in case of occurrence, they share the loss according to the liability sharing rule in force (either per capita or proportional). In order to identify the impact of information disclosure, we run four treatments, by varying both the presence of an identification mechanism and the liability rule. Under a per capita rule of apportionment, in case of harm occurring, the damages are split equally between the four players of the group. Under a proportional rule, each player is held liable for the harm in proportion to their (lack of) investment to avoid it.

Our theoretical predictions are that a proportional rule should, everything else being equal, raise higher investments than a per capita rule, the intuition being that bearing a share of the damage which depends on relative contributions calls off the free riding implied by a per capita rule. Most importantly, we also find theoretically that information disclosure should raise investments to a higher extent under a PC rule than under a PR rule if agents are sensitive to disesteem.

Our results confirm our predictions. We find that information disclosure is efficient under a PC rule, leading to a significant increase in contributions, whereas it has no significant impact under a PR rule. While a PR rule provides higher incentives to contribute to decreasing the level of expected harm than a PC rule, adding an identification mechanism to the PC rule makes it as efficient as the PR rule. The higher effectiveness of the identification mechanism under a PC rule can be explained by the different social costs of non-contribution under the two rules. Indeed, the PR rule provides subjects with higher pecuniary incentives to contribute than the PC rule. As a consequence, there is less merit in contributing (or not being a low contributor) under PR than under PC, and low contribution under PR is ‘paid’ by a higher share of liability, that reduces the free-riding burden on others. Low contribution is thus less stigmatizing under PR than under

PC.

We believe that the fact that disclosure acts more effectively under a PC rule than under a PR rule is of interest. The first reason is that this result contrasts in a way with the existing literature which concludes that information disclosure systematically has a positive impact on firms' environmental performance (Blackman et al., 2004; Garcia et al., 2007; Bennear and Olmstead, 2008; Garcia et al., 2009; Powers et al., 2011; Huet-Vaughn et al., 2018). A second reason lies in the fact that, although the PR rule is used in some countries, its cost-effectiveness ratio might be questioned, as it requires much more information to be collected than the PC rule, and especially information on the best available technologies or practices, in order to evaluate the firms' deviations with respect to them. Moreover, from a political economy perspective, implementing a per capita apportionment of harm could be easier than a proportional one, which could also be seen as a source of uncertainty for firms. In contrast to the PR rule, information disclosure coupled with a PC rule requires less information, as it only needs a ranking of each firm's practices. Such a mechanism is indeed implemented in countries in which enforcement of regulations is weak.²³ This is notably achieved in the environmental field by non-governmental organizations and whistleblowers, which thus play a key role here in terms of information search. Adding information disclosure mechanisms in a PC rule legal context could be a cost-effective alternative to implementing a PR rule and this could be facilitated by public as well as private disclosure.

This chapter is, to our knowledge, the first to investigate the impact of information disclosure by considering different legal contexts. But it is only a first step in that direction. We adopt a liability sharing context, but extensions should consider other contexts in order to determine whether this result may reflect a pattern. In particular, the possibility for victims, or citizens at large, to express disapproval or feel disesteem could be introduced into the analysis as a pushing factor for individual contributions to reduce the expected harm. Moreover, introducing citizens into the analysis could also open the door to the possibility of miscommunication by the agents causing the (expected) harm. As shown in Bramoullé and Orset (2018), firms are able to discredit information revealing their supposed detrimental actions by producing and publicizing scientific evidence which balances it and/or advertising on the virtues of their activities. Such actions might lessen the incentivizing power of information disclosure mechanisms. Faced with the possibility

²³See the example of Indonesia in Afsah et al. (1996).

of making a choice between preventive efforts to reduce the expected harm (as considered in this chapter) on the one hand, and miscommunication efforts to reduce stigmatization on the other, the proportional liability sharing rule could regain some virtues, relative to the per capita rule.

Bibliography of Chapter 1

- Afsah, S., Laplante, B., and Wheeler, D. (1996). Controlling industrial pollution - a new paradigm. *The World Bank - Policy Research Working Paper*, 1672.
- Andreoni, J. (1988). Why free ride?: Strategies and learning in public goods experiments. *Journal of Public Economics*, 37(3):291–304.
- Andreoni, J. and Petrie, R. (2004). Public goods experiments without confidentiality: a glimpse into fund-raising. *Journal of Public Economics*, 88:1605–1623.
- Angelova, V., Armantier, O., Attanasi, G., and Hiriart, Y. (2014). Relative performance of liability rules: Experimental evidence. *Theory and Decision*, 77:531–556.
- Benbear, L. S. and Olmstead, S. M. (2008). The impacts of the “right to know”: Information disclosure and the violation of drinking water standards. *Journal of Environmental Economics and Management*, 56(2):117–130.
- Blackman, A., Afsah, S., and Ratunanda, D. (2004). How do public disclosure pollution control programs work? evidence from indonesia. *Human Ecology Review*, 11(3):235–246.
- Blanco, E., Haller, T., and Walker, J. M. (2017). Externalities in appropriation: responses to probabilistic losses. *Experimental Economics*, 20:793–808.
- Blanco, E., Lopez, M. C., and Walker, J. M. (2016). The opportunity costs of conservation with deterministic and probabilistic degradation externalities. *Environmental and Resource Economics*, 64:255–273.
- Boun My, K. and Ouyard, B. (2019). Nudge and tax in an environmental public goods experiment: Does environmental sensitivity matter? *Resource and Energy Economics*, 55:24–48.
- Bramoullé, Y. and Orset, C. (2018). Manufacturing doubt. *Journal of Environmental Economics and Management*, 90:119–133.
- Brown, J. (1973). Towards an economic theory of liability. *Journal of Legal Studies*, 2:323–349.
- Brown-Kruse, J. and Hummels, D. (1993). Gender effects in laboratory public goods contributions. *Journal of Economic Behavior & Organization*, 22:255–267.

- Buchens, C., Deffains, B., and Palermo, A. (2019). Stigmatization, liability and public enforcement of law. *Revue d'économie politique*, 129:235–259.
- Calabresi, G. (1970). *The Cost of Accidents, a Legal and Economic Analysis*. Yale University Press.
- Capelle-Blancard, G. and Laguna, M.-A. (2010). How does the stock market respond to chemical disasters? *Journal of Environmental Economics and Management*, 59:192–205.
- Deffains, B., Espinosa, R., and Fluet, C. (2019). Laws and norms: Experimental evidence with liability rules. *International Review of Law and Economics*, 60:1–16.
- Deffains, B. and Fluet, C. (2013). Legal liability when individuals have moral concerns. *Journal of Law, Economics, and Organization*, 29:930–955.
- Eckel, C. C. and Grossman, P. J. (2002). Sex differences and statistical stereotyping in attitudes toward financial risk. *Evolution and Human Behavior*, 23(4):281–295.
- Endres, A. and Bertram, R. (2006). The development of care technology under liability law. *International Review of Law and Economics*, 26:503–518.
- Endres, A., Bertram, R., and Rundshagen, B. (2008). Environmental liability law and induced technical change: The role of spillovers. *Journal of Institutional and Theoretical Economics*, 164:254–279.
- Ferrey, S. (2009). Inverting the law: Superfund hazardous substance liability and supreme court reversal of all federal circuits. *William & Mary Environmental Law and Policy Review*, 33:633–722.
- Flambard, V., Le Lec, F., and Romaniuc, R. (2020). How does risk affect collective participation? public good provision versus public bad prevention. Mimeo.
- Foulon, J., Lanoie, P., and Laplante, B. (2002). Incentives for pollution control: Regulation or information? *Journal of Environmental Economics and Management*, 44:169–187.
- Gächter, S. and Renner, E. (2010). The effects of (incentivized) belief elicitation in public goods experiments. *Experimental Economics*, 13(3):364–377.

- García, J. H., Afsah, S., and Sterner, T. (2009). Which firms are more sensitive to public disclosure schemes for pollution control? evidence from indonesia's proper program. *Environmental and Resource Economics*, 42:151–168.
- García, J. H., Sterner, T., and Afsah, S. (2007). Public disclosure of industrial pollution: the proper approach for indonesia? *Environment and Development Economics*, 12(6):739–756.
- Gonenc, H. and Scholtens, B. (2017). Environmental and financial performance of fossil fuel firms: A closer inspection of their interaction environmental and financial performance of fossil fuel firms: A closer inspection of their interaction environmental and financial performance of fossil fuel firms: A closer inspection of their interaction. *Ecological Economics*, 132:307–328.
- Greiner, B. (2015). Subject pool recruitment procedures: organizing experiments with orsee. *Journal of the Economic Science Association*, 1(1):114–125.
- Huet-Vaughn, E., Muller, N., and Hsu, Y.-C. (2018). Livestreaming pollution: a new form of public disclosure and a catalyst for citizen engagement? NBER working paper 24664.
- Jacob, J., Lambert, E.-A., and Garcia, S. (2022). Efficiency of Liability-Sharing Rules: An Experimental Case. *Journal of Institutional and Theoretical Economics (JITE)*, 178(1):1–42.
- Jacquet, J. and Jamieson, D. (2016). Soft but significant power in the paris agreement. *Nature Climate Change*, 6(643-646).
- Kahneman, D. and Tversky, A. (1973). Availability: A heuristic for judging frequency and probability. *Cognitive Psychology*, 5(2):207–232.
- Keser, C. and Montmarquette, C. (2008). Voluntary contributions to reduce expected public losses. *Journal of Economic Behavior & Organization*, 66:477–491.
- Konar, S. and Cohen, M. A. (1997). Information as regulation: The effect of community right to know laws on toxic emissions. *Journal of Environmental Economics and Management*, 32:109–124.
- Kornhauser, L. and Schotter, A. (1990). An experimental study of single-actor accidents. *The Journal of Legal Studies*, 19:203–233.

- Kornhauser, L. and Schotter, A. (1992). An experimental study of two-actor accidents. *C.V. Starr Center for applied economics - economic research report*.
- Kornhauser, L. A. and Revesz, R. L. (1989). Sharing damages among multiple tortfeasors. *The Yale Law Journal*, 98:831–884.
- Kornhauser, L. A. and Revesz, R. L. (1990). Apportioning damages among potentially insolvent actors. *The Journal of Legal Studies*, 19:617–651.
- Nielsen, K. (2019). Dynamic risk preferences under realized and paper outcomes. *Journal of Economic Behavior & Organization*, 161:68–78.
- Pien, C.-P. (2020). Local environmental information disclosure and environmental non-governmental organizations in chinese prefecture-level cities. *Journal of Environmental Management*, 275.
- Pinkowski, B. (1996). Simplifying cercla defenses to liability. *The Urban Lawyer*, 28:197–221.
- Powers, N., Blackman, A., Lyon, T. P., and Narain, U. (2011). Does disclosure reduce pollution? evidence from india’s green rating project. *Environment and Resource Economics*, 50:131–155.
- Rege, M. and Telle, K. (2004). The impact of social approval and framing on cooperation in public good situations. *Journal of Public Economics*, 88:1625–1644.
- Samek, A. S. and Sheremeta, R. S. (2014). Recognizing contributors: an experiment on public goods. *Experimental Economics*, 17:673–690.
- Schatz, A. (2008). Regulating greenhouse gases by mandatory information disclosure. *Virginia Environmental Law Journal*, 26(1):335–393.
- Shavell, S. (1980). Strict liability versus negligence. *Journal of Legal Studies*, 9:1–25.
- Soetevent, A. (2005). Anonymity in giving in a natural context - a field experiment in 30 churches. *Journal of Public Economics*, 89:2301–2323.
- Thaler, R. and Johnson, E. (1990). Gambling With the House Money and Trying to Break Even: The Effects of Prior Outcomes on Risky Choice. *Management Science*, 36:643–660.
- Tietenberg, T. (1998). Disclosure strategies for pollution control. *Environmental and Resource Economics*, 11:587–602.

Appendix 1.A Proof of Prediction 1

A comparison between x_i^{PR} and x_i^{PC} consists in comparing (1.7) with (1.5), that is:

$$\frac{\partial E[\Pi_i^{PC}(x_i, x_j, x_k, x_l)]}{\partial x_i} = 0 \Leftrightarrow -\frac{\partial p(x_i, x_j, x_k, x_l)}{\partial x_i} \frac{H}{4} = -\frac{\partial R(x_i)}{\partial x_i}$$

with:

$$\begin{aligned} \frac{\partial E[\Pi_i^{PR}(x_i, x_j, x_k, x_l)]}{\partial x_i} &= 0 \\ \Leftrightarrow -\left[\frac{\partial \gamma_i(x_i, x_j, x_k, x_l)}{\partial x_i} \cdot p(x_i, x_j, x_k, x_l) + \frac{\partial p(x_i, x_j, x_k, x_l)}{\partial x_i} \cdot \gamma_i(x_i, x_j, x_k, x_l) \right] H &= -\frac{\partial R(x_i)}{\partial x_i} \end{aligned}$$

We observe that both marginal costs of care are equal, but marginal benefits are different.

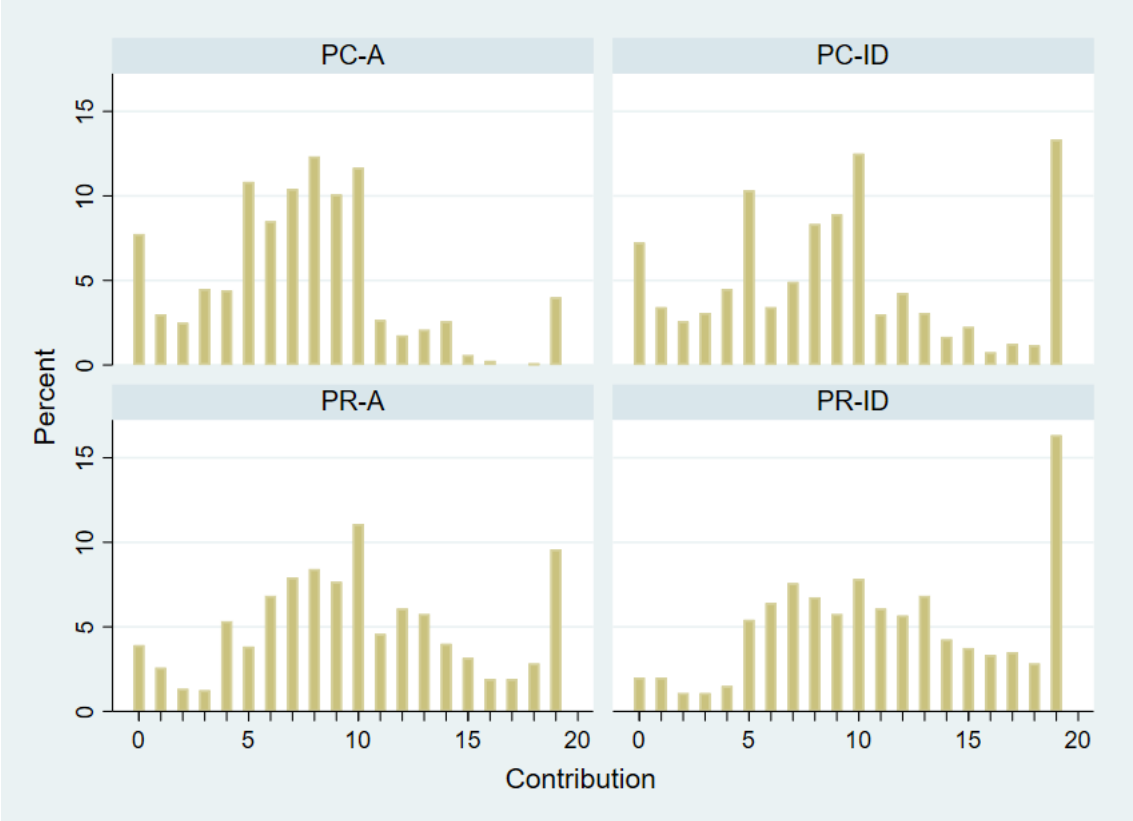
$x_i^{PR} > x_i^{PC}$ can occur if, for $x_i = x_i^{PC}$, we have :

$$\begin{aligned} & -\left[\frac{\partial \gamma_i(x_i^{PC}, x_j, x_k, x_l)}{\partial x_i} \cdot p(x_i^{PC}, x_j, x_k, x_l) + \frac{\partial p(x_i^{PC}, x_j, x_k, x_l)}{\partial x_i} \cdot \gamma_i(x_i^{PC}, x_j, x_k, x_l) \right] H > \\ & -\frac{\partial p(x_i^{PC}, x_j, x_k, x_l)}{\partial x_i} \frac{H}{n} \\ \Rightarrow & -\frac{\partial \gamma_i(x_i^{PC}, x_j, x_k, x_l)}{\partial x_i} \cdot p(x_i^{PC}, x_j, x_k, x_l) > -\frac{\partial p(x_i^{PC}, x_j, x_k, x_l)}{\partial x_i} \left(\frac{1}{n} - \gamma_i(x_i^{PC}, x_j, x_k, x_l) \right) \\ \Rightarrow & 1 > \frac{-\frac{\partial p(x_i^{PC}, x_j, x_k, x_l)}{\partial x_i} \left(\frac{1}{n} - \gamma_i(x_i^{PC}, x_j, x_k, x_l) \right)}{-\frac{\partial \gamma_i(x_i^{PC}, x_j, x_k, x_l)}{\partial x_i} \cdot p(x_i^{PC}, x_j, x_k, x_l)} \end{aligned}$$

Note that this condition is always satisfied whenever $\frac{1}{n} - \gamma_i(x_i^{PC}, x_j, x_k, x_l) \leq 0$, i.e., when, for $x_i = x_i^{PC}$, the share of liability under the proportional rule is higher than or equal to the per capita rate. Since the proportional rule reduces to the per capita one when the contributions of all agents are equal, we deduce that this condition is satisfied in the symmetric case we consider.

Appendix 1.B Distribution of contributions per treatment

Figure 1.A: Distribution of contributions per treatment



Appendix 1.C Econometric results

Table 1.A: Tobit estimations

	Restart effects	PC	PR
	(1)	(2)	(3)
PC-ID	1.982** (1.011)	1.736* (0.963)	
PR-A	2.695*** (1.014)		
PR-ID	4.268*** (1.019)		1.345 (1.060)
Loss _{p-1}	0.524*** (0.13)	0.606*** (0.161)	0.433** (0.208)
AveragePartners _{p-1}	0.289*** (0.02)	0.309*** (0.026)	0.241*** (0.03)
Period	-.07*** (0.008)	-.092*** (0.014)	-.080*** (0.018)
1 st period in 2 nd group	0.76*** (0.2)		
1 st period in 3 rd group	0.699*** (0.196)		
1 st period in 4 th group	0.694*** (0.2)		
Period*PC-ID		0.031 (0.02)	
Period*PR-ID			0.032 (0.025)
Gamble	-.368 (0.288)	-.255 (0.369)	-.254 (0.427)
Risk-seeking	-.452** (0.187)	-.327 (0.243)	-.712*** (0.276)
Female	-2.236*** (0.778)	-1.452 (0.984)	-2.638** (1.147)
Age	0.13 (0.145)	0.064 (0.179)	0.138 (0.222)
Econ-manag	-.963 (0.781)	-2.910*** (0.998)	1.064 (1.137)
Distrust	0.891 (0.807)	2.307** (1.079)	-.771 (1.132)
Earnings	-.443 (0.73)	-2.590*** (0.979)	1.724* (1.022)
Constant	7.405** (3.752)	8.317* (4.522)	10.866* (5.877)
Obs.	4560	2280	2280
Left-censored obs.	245	177	68
Right-censored obs.	487	194	293

Estimated standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Appendix 1.D Instructions

Translated from French to English.

In red, the elements that change in the instructions for PR.

In blue, the elements that change in the instructions for ID.

Thank you for participating in this experiment on the economics of decision making. In this experiment you will have the opportunity to make money. The amount of your payoff will depend on **your decisions and the decisions of other participants**. Therefore, we ask you to read these instructions carefully since they will help you understand the experiment. All your decisions are **anonymous**. You will give your choices to the computer in front of which you are sitting.

From now on, communication is no longer permitted. Please switch off your mobile phone as well. If you have a question, raise your hand and an experimenter will come and answer you in private.

This experiment comprises 2 parts. You have received the instructions for part 1. Each time you finish a part, you will get the instructions for the next one. All participants have the same instructions.

The earnings you can collect by taking part in this experiment are expressed in ECUs (Experimental Currency Units). At the end of each part, your earnings, in ECUs, will be converted in euros according to the conversion rate that applies to the part in question. At the end of the experiment, the gains you will have earned, converted into euros, will be paid to you in cash privately.

PART 1

For this part, the conversion rate is **1 ECU = 0.075 €**.

This first part of the experiment comprises 20 periods. During this part, you and 3 other randomly chosen anonymous participants will form a group of 4 persons. However, this group will not remain the same during these 20 periods. Every 5 periods, you will be randomly reallocated to a new group of 4 persons. Within this new group, you may interact with participants you have already played with (in a previous group). However, when this happens, you will not be informed.

At the beginning of this part, you will receive 200 ECUs. It is your initial wealth. In addition to

your initial wealth, you will receive an endowment of 19 ECUs at the beginning of each period. In each period a loss of 200 ECUs can occur randomly. [PC: If this loss arises, each member of the group will bear $\frac{1}{4}$ of the cost, that is, 50 ECUs.] [PR: If this loss arises, the members of the group will have to bear it collectively.]

Tasks

Task 1) In every period, you will have to choose how many ECUs from your endowment (integer between 0 and 19) you are willing to give in order to decrease the probability of the loss of 200 ECUs occurring; and how many ECUs you want to keep for yourself.

The probability of the loss occurring decreases as your contribution **and** the contributions of the 3 other members of the group increase. Nevertheless, when you make your decision, you will not know the choice of the 3 other members and the four of you will make your decisions simultaneously.

In order to help you understand how the probability changes with the decisions of each member of the group, you can refer to Table 1. In this table, your choice of contribution is indicated in the first column. The first line represents the average contribution of the 3 other members of the group. The probabilities of occurrence of a loss according to your contribution (1st column) and the average contribution of the three other members (1st line) are indicated inside the table.

Let us take two examples at random:

Example 1: suppose that one member of the group decided to contribute 4 ECUs, another one 0 ECU and the last one 9 ECUs. Their average contribution is thus 4.3 ECUs (indeed each one of them contributed on average $\frac{4+0+9}{3} = 4.3$ ECUs). If you decide to contribute 14 ECUs, the probability of occurrence of the loss is, in this case, of 16.3%.

Example 2: suppose that one member of the group decided to contribute 10 ECUs, another one 14 ECUs and the last one 18 ECUs. Their average contribution is thus 14 ECUs (indeed each one of them contributed on average $\frac{10+14+18}{3} = 14$ ECUs). If you decide to contribute 6 ECUs, the probability of occurrence of the loss is, in this case, of 9.9%.

Note that if the 4 members contribute the minimum amount (0 ECU), the probability of the loss occurring is equal to 100% (the loss occurs with certainty); on the contrary, if the 4 members make the maximum contribution (19 ECUs), the probability decreases to 0% (there is no loss).

Task 2) In every period, once you will have made your contribution decision, you will have to indicate what you think the other members decided. You will indicate what you think the average

contribution of the 3 other members (integer between 0 and 19) will be for this period. The closer your answer is to the actual one, the more you earn. If your estimation is correct or not more than 0.5 ECU away from the actual average contribution, you will earn 6 additional ECUs. If your answer is further off than 0.5 ECU, you will earn 3 ECUs divided by the (absolute) distance between your estimation and the actual value.

Let us take two examples at random:

Example 1: you believe that the 3 other members of the group will contribute on average 5 ECUs. Thus, you tell the computer 5. It turns out that the exact answer was 5.3 ECUs. You earn 6 ECUs because your answer is only 0.3 ECU away from the actual one and this gap is lower than 0.5.

Example 2: you believe that the 3 other members of the group will contribute on average 17 ECUs. Thus, you tell the computer 17. It turns out that the exact answer was 12.7 ECUs. You earn $\frac{3}{4.3}$ ECUs (i.e., 0.7 ECU) because your answer is 4.3 ECUs away from the actual one and this gap is higher than 0.5.

Once each member has expressed their belief on the average contribution of the three others, the computer will determine randomly, according to the probability corresponding to the decisions of the 4 members of the group, whether the loss occurs or not.

The periods are independent from each other, meaning that if a loss occurs in a period, it does not affect the probability of occurrence in the next ones.

Earnings

[PR: If a loss of 200 ECUs occurs, you will have to bear a share that depends on your contribution and on the contributions of the 3 other members of the group. The more you contribute with respect to the contribution of the 3 other members, the lower this share. If the four of you contribute the same amount, the share you will all have to bear will be identical.

In order to help you understand how your share changes with the decisions of each member of the group, you can refer to Table 2. In this table, your choice of contribution is indicated in the first column. The first line represents the average contribution of the 3 other members of the group. The shares of the loss you will have to bear, if it occurs, according to your contribution (1st column) and the average contribution of the 3 other members (1st line) are indicated inside the table.

Let us take one example at random:

Example 1: suppose that one member of the group decided to contribute 10 ECUs, another one 17 ECUs and the last one 5 ECUs. Their average contribution is thus 10.7 ECUs (indeed each one of them contributed on average $\frac{10+17+5}{3} = 10.7$ ECUs). If you decide to contribute 13 ECUs, the share of the loss you will have to bear, if it happens, is, in this case, 38.7 ECUs.]

Your earnings in every period are the sum of two amounts (earnings for task 1 and earnings for task 2) and depend on the occurrence of the loss:

[PC:

19 (your endowment) - your contribution (0, 1, 2, ... 19) - 50 ($\frac{1}{4}$ of the loss) + earnings for task 2 If the loss occurs

19 (your endowment) - your contribution (0, 1, 2, ... 19) + earnings for task 2 If the loss does not occur]

[PR:

19 (your endowment) - your contribution (0, 1, 2, ... 19) - your share of the loss + earnings for task 2 If the loss occurs

19 (your endowment) - your contribution (0, 1, 2, ... 19) + earnings for task 2 If the loss does not occur]

At the end of each period, you will be informed of the total contribution of your group, the resulting probability, the occurrence of the loss and your earnings for this period (earnings for task 1 and for task 2).

[ID: At the end of the 20 periods, 4 participants will randomly draw a period and will say it aloud to the other participants. These 4 periods will be used to calculate your average contribution. For example, if you contributed 3 ECUs, 14 ECUs, 0 ECU and 8 ECUs during the 4 selected periods, your average contribution is $\frac{3+14+0+8}{4} = 6.25$ ECUs. The picture and the name of the 5 persons who contributed the least on average (among all the participants) will be **displayed on the computer screen of each participant at the end of the experiment**. If, in case of equality of average contribution, there are more than 5 persons who contributed the least, all of them will be viewed.]

At the end of the experiment, only 1 in 20 periods will actually be paid according to the conversion rate in euros. One participant will randomly draw a period in order to calculate the earnings for this first part. Each period has the same probability of being selected.

Therefore, your earnings for this first part are equal to: 200 (your initial wealth) + earnings from

Figure 1.C: Table 2 - Loss

Table 2: Evolution of the share of the loss (in ECUs) you will have to bear if it happens according to your contribution (1st column) and the average contribution of the 3 other members of the group (1st line)

Your contribution	Average contribution of the 3 other members of the group																												
	0	0.3	0.7	1	1.3	1.7	2	2.3	2.7	3	3.3	3.7	4	4.3	4.7	5	5.3	5.7	6	6.3	6.7	7	7.3	7.7	8	8.3	8.7	9	9.3
0	50.0	50.7	51.4	52.1	52.8	53.5	54.3	55.1	55.9	56.7	57.6	58.5	59.4	60.3	61.3	62.3	63.3	64.4	65.5	66.7	67.9	69.1	70.4	71.7	73.1	74.5	76.0	77.6	79.2
1	48.0	48.6	49.3	50.0	50.7	51.5	52.2	52.9	53.6	54.5	55.4	56.3	57.1	58.1	59.0	60.0	61.0	62.1	63.2	64.3	65.5	66.7	67.9	69.2	70.6	72.0	73.5	75.0	76.6
2	45.9	46.6	47.2	47.9	48.6	49.3	50.0	50.7	51.5	52.3	53.1	54.0	54.8	55.7	56.7	57.6	58.6	59.6	60.7	61.8	63.0	64.2	65.4	66.7	68.0	69.4	70.8	72.3	73.9
3	43.8	44.4	45.1	45.7	46.4	47.1	47.8	48.5	49.2	50.0	50.8	51.6	52.5	53.3	54.2	55.1	56.1	57.1	58.2	59.3	60.4	61.5	62.7	64.0	65.3	66.7	68.1	69.6	71.1
4	41.7	42.3	42.9	43.5	44.1	44.8	45.5	46.2	46.9	47.6	48.4	49.2	50.0	50.8	51.7	52.6	53.6	54.5	55.6	56.6	57.7	58.8	60.0	61.2	62.5	63.8	65.2	66.7	68.2
5	39.4	40.0	40.6	41.2	41.8	42.4	43.1	43.8	44.4	45.2	45.9	46.7	47.5	48.3	49.1	50.0	50.9	51.9	52.8	53.8	54.9	56.0	57.1	58.3	59.6	60.9	62.2	63.6	65.1
6	37.1	37.7	38.2	38.8	39.4	40.0	40.6	41.3	41.9	42.6	43.3	44.1	44.8	45.6	46.4	47.3	48.1	49.1	50.0	51.0	52.0	53.1	54.2	55.3	56.5	57.8	59.1	60.5	61.9
7	34.8	35.3	35.8	36.4	36.9	37.5	38.1	38.7	39.3	40.0	40.7	41.4	42.1	42.9	43.6	44.4	45.3	46.2	47.1	48.0	49.0	50.0	51.1	52.2	53.3	54.5	55.8	57.1	58.5
8	32.4	32.8	33.3	33.8	34.4	34.9	35.5	36.1	36.7	37.3	37.9	38.6	39.3	40.0	40.7	41.5	42.3	43.1	44.0	44.9	45.8	46.8	47.8	48.9	50.0	51.2	52.4	53.7	55.0
9	29.9	30.3	30.8	31.3	31.7	32.3	32.8	33.3	33.9	34.5	35.1	35.7	36.4	37.0	37.7	38.5	39.2	40.0	40.8	41.7	42.6	43.5	44.4	45.5	46.5	47.6	48.8	50.0	51.3
10	27.3	27.7	28.1	28.6	29.0	29.5	30.0	30.5	31.0	31.6	32.1	32.7	33.3	34.0	34.6	35.3	36.0	36.7	37.5	38.1	39.1	40.0	40.9	41.9	42.9	43.9	45.0	46.2	47.4
11	24.6	25.0	25.4	25.8	26.2	26.7	27.1	27.6	28.1	28.6	29.1	29.6	30.2	30.8	31.4	32.0	32.7	33.3	34.0	34.8	35.6	36.4	37.2	38.1	39.0	40.0	41.0	42.1	43.2
12	21.9	22.2	22.6	23.0	23.3	23.7	24.1	24.6	25.0	25.5	25.9	26.4	26.9	27.5	28.0	28.6	29.2	29.8	30.4	31.1	31.8	32.6	33.3	34.1	35.0	35.9	36.8	37.8	38.9
13	19.0	19.4	19.7	20.0	20.3	20.7	21.1	21.4	21.8	22.2	22.6	23.1	23.5	24.0	24.5	25.0	25.5	26.1	26.7	27.3	27.9	28.6	29.3	30.0	30.8	31.6	32.4	33.3	34.3
14	16.1	16.4	16.7	16.9	17.2	17.5	17.9	18.2	18.5	18.9	19.2	19.6	20.0	20.4	20.8	21.3	21.7	22.2	22.7	23.3	23.8	24.4	25.0	25.6	26.3	27.0	27.8	28.6	29.4
15	13.1	13.3	13.6	13.8	14.0	14.3	14.5	14.8	15.1	15.4	15.7	16.0	16.3	16.7	17.0	17.4	17.8	18.2	18.6	19.0	19.5	20.0	20.5	21.1	21.6	22.2	22.9	23.5	24.2
16	10.0	10.2	10.3	10.5	10.7	10.9	11.1	11.3	11.5	11.8	12.0	12.2	12.5	12.8	13.0	13.3	13.6	14.0	14.3	14.6	15.0	15.4	15.8	16.2	16.7	17.1	17.6	18.2	18.8
17	6.8	6.9	7.0	7.1	7.3	7.4	7.5	7.7	7.8	8.0	8.2	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.8	10.0	10.3	10.5	10.8	11.1	11.4	11.8	12.1	12.5	12.9
18	3.4	3.5	3.6	3.6	3.7	3.8	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.7	4.8	4.9	5.0	5.1	5.3	5.4	5.6	5.7	5.9	6.1	6.3	6.5	6.7	
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

N.B. The values indicated on your screen may differ by 0.1 from the ones in the table.
Please do not write on the tables.

PART 2

For this part, the conversion rate is **1 ECU = 0.25 €**.

In this part, you will have only one decision to make. You will have to choose **one** gamble from 5 different gambles. Your earnings for this part will depend on the outcome of the gamble. For each gamble, there are 2 possible earnings: earnings from situation A and earnings from situation B. Each situation has a 50% chance of happening.

In order to determine your earnings for this part, the computer will toss a coin virtually. If it is heads, situation A will happen and if it is tails, situation B will happen. Your earnings will correspond to the earnings of the winning situation of the gamble you will have chosen.

[Displayed on the screen:]

Gamble	Situation A (50%)	Situation B (50%)
1	12 ECUs	12 ECUs
2	18 ECUs	10 ECUs
3	24 ECUs	8 ECUs
4	30 ECUs	6 ECUs
5	36 ECUs	4 ECUs

POST-EXPERIMENTAL QUESTIONNAIRE

1. Your age:

2. Your sex: *Male; Female*

3. Your degree: *Bachelor; Master; PhD*

4. Your field of study: *Law; Economics and Management; Literature and Languages; Hard sciences; Psychology and Sociology; Political science; Other (please specify)*

5. In everyday life, do you think that you are a person who rather takes risks or a rather careful person? Please indicate on a scale of 0 to 10 where do you think you stand; 0 standing for a very careful person and 10 for a person who loves taking risks. *0; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10*

6. In everyday life, do you think that you try to help other people or that you only care about your own concerns? Please indicate on a scale of 0 to 10 where do you think you stand; 0 standing for a person who loves helping others and 10 for a person who acts in their

own interest. 0; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10

7. Generally speaking, do you think that we can trust most people or that we must be very careful with people? *We can trust most people; We must be very careful with people*

8. During the experiment, which information did guide your decisions? *Only your payoff; Your payoff and others' payoff such that they do not have less than you; Your payoff and others' payoff such that they do not have more than you; Your payoff and others' payoff such that they have no more and no less than you*

9. Which criteria did guide your decisions during the experiment?

10. In your opinion, what was the objective of this experiment?

Chapter 2

“If you think you are too small to make a difference, try sleeping with a mosquito.”

Dalai Lama

Climate policies under income inequality

Mathieu Lefebvre & Sarah Van Driessche

In this chapter, we propose an original experiment to assess the effect of income inequality on the efforts individuals are willing to make to face climate change. Subjects must decide between mitigation or adaptation policies, i.e., they have to choose between decreasing the probability of a climate event for the group or protecting themselves from that damage. This choice can be assimilated to a social dilemma where mitigation is a public good and adaptation is a private good. Between treatments, we vary the distribution of income within groups so that we can modify the degree of inequality. We find that group contributions to mitigation are not affected by the degree of inequality. At the individual level, the results show that richer subjects invest more in absolute terms than poorer ones but not in relative terms. Among poor subjects, we witness an ‘income effect’ while this is not true among rich ones. The econometric results highlight the major role of social preferences (i.e., aversion to disadvantageous and advantageous inequality) in the choice to mitigate or to adapt of rich subjects.

Contents

2.1	Introduction	71
2.2	Experimental design	74
2.2.1	Main game	74
2.2.2	Treatments	76
2.2.3	Inequality and risk preferences, environmental sensitivity	78
2.2.4	Procedure	79
2.3	Predictions	80
2.4	Results	83
2.4.1	Group contributions	83
2.4.2	Within-treatment comparisons	84
2.4.3	Between-treatment comparisons	87
2.4.4	Individual decisions	89
2.5	Discussion and conclusion	94
	Bibliography of Chapter 2	96
	Appendices of Chapter 2	102
2.A	Average contributions over time per treatment and type of subjects	102
2.B	Instructions	102

2.1 Introduction

In face of climate change and environmental challenges, the question of the link between income distribution and environmental policies has regained much attention in the scientific and public debates (Cassin et al., 2021). In particular, the rising of income and wealth inequalities observed around the world (Alvaredo et al., 2017) raises the question of the mutual worsening of environmental and socio-economic situations. The last report by the Intergovernmental Panel on Climate Change (IPCC, 2021) emphasized the role that climate change could have on inequality of income, and recent studies have been dedicated to the study of the effect of environmental policies on the income inequality (Aubert and Chiroleu-Assouline, 2019; Jacobs and van der Ploeg, 2019). However, the effect that inequality of income can have on climate change, in particular through the choice of environmental policies, also matters. Indeed social and income inequalities have been found to affect collective action and inhibit cooperation (Baland et al., 2010), which in turn may exacerbate the environmental degradation and prevent from implementing efficient policies (Berthe and Elie, 2015).

Looking at individual decisions, the question is what type of effort are people willing to make to address climate change and how this may change according to their relative income. Individuals can decide to adopt mitigation policies that reduce the risk of environmental damage (for example using low-carbon or renewable energy) or to protect themselves against the consequences of climate change through investments in adaptation (such as erecting more sustainable buildings for example). While mitigation can be viewed as a public good, investment in adaptation is best described as a private good (Hasson et al., 2010). The choice of one or another can then be assimilated to a social dilemma wherein what is individually rational is not necessarily socially optimal. Although there is a large literature on social dilemmas in experimental and behavioral economics¹, few studies have been dedicated to the mitigation-adaptation trade-off.² Furthermore, none has looked at the effect of income inequality on the choice of an environmental policy. Although, income heterogeneity has been found to have unclear effects on the level

¹There is a large literature on social dilemmas dealing with individual decisions to contribute to public goods (Ledyard, 1995), the economic incentives to cooperate (see e.g., Ostrom, 1990; Fehr and Gächter, 2000; Masclet et al., 2003; Peeters and Vorsatz, 2013), the role of social information (Andreoni and Petrie, 2004; Frey and Meier, 2004; Cason et al., 2016) and the effect of heterogeneity on incentives efficiency (Gangadharan et al., 2017; Nikiforakis et al., 2012; Reuben and Riedl, 2013).

²Two well-known studies are Hasson et al. (2010) and Hasson et al. (2012). A more recent one is McEvoy et al. (2022).

of contributions to a public good (Chan et al., 1996, 1999; Keser et al., 2014; Cherry et al., 2005; Paetzl and Traub, 2017) and could thus also affect the choice between mitigation and adaptation.

In this chapter, we present an original contextualized experiment to study the individual decisions to invest resources in mitigation and adaptation policies when we vary in a between-treatment design the income distribution. Following the previous work by Hasson et al. (2010) and in order to reflect the actual dynamics of climate change, our design is focused on the possibility of an environmental damage that entails a loss which is uncertain. Group members have to decide how much to invest in decreasing the probability of occurrence of this loss for the whole group (mitigation) and how much to allocate to reducing the extent of the loss for themselves (adaptation). Between treatments, we manipulate the distribution of income within groups in order to compare the resulting policy choices from a situation in which there is no inequality to situations with inequality. It allows us to estimate how (the level of) income inequality affects the trade-off between adaptation and mitigation. This is particularly important since both types of policy do not protect every groups of population similarly. As pointed out by Islam and Winkel (2017), people differ in their ability to cope and recover from climate change-related damages. The disadvantaged people are more susceptible to damage. The choice of an environment policy that would cover also the poorest people (i.e., mitigation) could therefore be beneficial for them. Our framework thus looks at redistributive efforts according to the level of income inequality when people face common environmental damages.

The chapter contributes to a growing literature interested in the relationship between income inequality and environmental policy. While some papers have studied how environmental programs affect income inequality (see e.g., Aubert and Chiroleu-Assouline, 2019; Jacobs and van der Ploeg, 2019), others have tried to understand how the income distribution shapes the environmental policy (Magnani, 2000; Cassin et al., 2021; Berthe and Elie, 2015). However, theoretical and empirical findings are rather mixed when it comes to the effects of economic inequality on environmental policies. Some studies show the existence of a negative relationship between inequality and environmental policy (Magnani, 2000; Eriksson and Persson, 2003; Kempf and Rossignol, 2007) while others like Heerink et al. (2001) point out the possibility that richer groups encourage environmental protection policies. At an aggregate level, one observes a non monotonic relationship between income inequality and environmental policy, such that for higher

levels of inequality, environmental public spending is reduced when it is already low (Cassin et al., 2021). Most of these studies have compared inequality across countries and very few have been interested in within-country inequality. Though initial inequality within a country may result in greater inequality due to the adverse effects of climate change.

The chapter is also related to studies in behavioral and experimental economics that are interested in social dilemmas and collective action problems. In particular, theoretical models predict that contributions to a public good should be unaffected by the level of inequality, the so-called neutrality theorem (Warr, 1983; Bergstrom et al., 1986). Some experiments have confirmed this conjecture by not finding any effect of income inequality on the level of contributions to a public good (Chan et al., 1996; Hofmeyr et al., 2007; Maurice et al., 2013; Keser et al., 2014; Isaac and Walker, 1988). On the contrary, the redistribution hypothesis assumes that increasing income inequality leads to an increased demand for redistribution, resulting in actual higher level of redistribution (Meltzer and Richard, 1981). Furthermore, non-traditional preferences such as altruism (Becker, 1974) and inequality aversion (Fehr and Schmidt, 1999), that have been found to predict well contribution behavior in public good experiments, may also predict some effects of inequality. In the particular case of income heterogeneity among subjects, Buckley and Croson (2006) have shown theoretically that under inequality aversion, contributions to a public good by richer subjects should be relatively higher while under altruism they should be absolutely higher. Their experimental results, however, are not consistent with either of these predictions. All these results have been found in public good experiments but behavior can be different in a public bad framework wherein contributions to mitigation reduce the probability of the loss while adaptation reduces the size of the loss. While public good games reveal rather high level of contributions (Ledyard, 1995), Hasson et al. (2010) and Hasson et al. (2012), in lab experiments that are close in design to ours, have found low level of investments in mitigation. They pointed out the role of trust and risk preferences in explaining these results. Also related to our framework, several studies have looked at collective-risk social dilemmas, where threshold contributions to a public good avoid the occurrence of a group loss under wealth differences (Tavoni et al., 2011; Burton-Chellew et al., 2013; Vasconcelos et al., 2014). In particular, Vasconcelos et al. (2014) have found that the rich generally contribute more than the poor and often compensate for the lower contribution of the latter.

Anticipating our results, we find that group contributions to mitigation do not depend on the

treatment condition (i.e., the degree of inequality). Within a group, we show that rich subjects invest more in absolute terms than poor ones but not in relative terms. We also witness an ‘income effect’ among poor subjects but not among rich ones. This is mainly explained by the fact that the choice to mitigate or to adapt of the rich is driven by social preferences (aversion to disadvantageous and advantageous inequality). These findings raise several questions that we discuss at the end of the chapter.

The rest of the chapter is organized as follows. In Section 2.2, we present the experimental design. Section 2.3 presents the predictions that we test with this experiment. In Section 2.4, we present the results and in Section 2.5, we discuss them and conclude.

2.2 Experimental design

2.2.1 Main game

The experiment consists of a repeated game played by groups of four subjects for ten periods. At the start of each period, subjects receive an initial endowment³ in ECUs and a climate budget in tokens that has to be spent on mitigation or on adaptation. It is made clear in the instructions that the climate budget must be shared in its entirety between the two measures in each period. Following Hasson et al. (2010), providing an external budget that needs to be entirely spent allows us to assess the decision between mitigation and adaptation. While it would make sense in terms of external validity to have an environment where participants can choose to spend any amount of their endowment on mitigation and/or adaptation or to do nothing, it would also prevent us from studying the trade-off between mitigation and adaptation measures, as in the real world of policy making.

Within each group, subjects are randomly assigned to a given type of player such that the endowment and the number of tokens vary according to this type.⁴ Subjects maintain their type

³The endowment serves to cover the risk of a loss.

⁴The initial endowment and the climate budget are based on a random allocation of subjects’ type. While earned and windfall endowments might lead to different results, Cherry et al. (2005) find that the origin of wealth does not affect the levels of contribution in a one-shot linear public good game with homogeneous and heterogeneous endowments. Also, in Erkal et al. (2011), participants must realize a real-effort task which determines the distribution of incomes within the group for the second part of the experiment. In that second part, the two subjects who ranked first and second in the first part of the experiment have the possibility to transfer part of their gains to the two other group members. The authors observe the same result when participants are not aware of the second task while participating in the first one, or when incomes are assigned by chance, i.e., there is no difference in giving between the two subjects who can redistribute.

for the duration of the experiment. As presented in Table 2.1, there are six different types of subjects with the lowest type (type 1) corresponding to the most disadvantaged subjects and the highest one (type 6) representing the wealthiest subjects. The composition of the group according to subjects types varies between treatments (see below) but within a treatment, it remains unchanged during all the periods of the game. The composition of the group is known to all members.

During each period, each group faces a risk of incurring a climatic event that can cause a loss of 150 ECUs for each group member. Subjects have to decide, simultaneously and without the possibility of communicating with the other group members, how they want to allocate their climate budget between the two measures: mitigation and adaptation.

A token invested in mitigation reduces the probability of occurrence of the climate event for the whole group. Thus, the probability of a loss diminishes as the members allocate their tokens to mitigation, and it is given by the following function:

$$p = 1 - \alpha \sum_{i=1}^4 x_i + \beta \left(\sum_{i=1}^4 x_i \right)^2 \quad (2.1)$$

where x_i is the number of tokens invested in mitigation by subject i , $i \in \{1, 2, 3, 4\}$. If none of the four subjects invests in mitigation, the probability is 1 and the climate event occurs with certainty. The parameters α and β are set to 0.015 and 0.000075 respectively, such that by investing the totality of their tokens in mitigation, subjects can decrease the probability down to 25%.⁵ In order to facilitate their decision making, subjects have access to sliders to simulate their level of investment in mitigation and the total level of investment of the other members of their group. The probability resulting from the position of the two sliders is then displayed on the screen.⁶

A token invested in adaptation, however, allows the subject to lower the size of their loss of endowment and only their loss in case of a climatic event. The reduction of the loss follows this

⁵There is still a risk of a climate damage even if the maximal group level of mitigation (i.e., 100 tokens) is reached. This reflects the fact that, as set out by the sixth assessment report of the IPCC, every region of the world will be challenged by changes in multiple Climatic Impact-Drivers (e.g., increased drought, river flooding, changes in snow).

⁶To avoid subjects needing mathematical skills in order to understand the function of probability, they were not given the functional form of that function but the simulation sliders instead. See the instructions in Appendix 2.B.

linear function:

$$L(x_i) = (1 - \theta (t_i - x_i)) H \quad (2.2)$$

where t_i stands for the initial number of tokens of subject i and H stands for the initial value of the loss which is equal to 150. The parameter θ is set equal to 0.01196. Here again, to facilitate the subjects' decision making, a table displaying the losses for every possible investment in adaptation is presented in the instructions (see the instructions in Appendix 2.B).

2.2.2 Treatments

The six different types of subjects are used to manipulate within group inequality as measured by the Gini index. The total group endowment and the total number of tokens remain constant across treatments (respectively 1000 ECUs and 100 tokens). We consider four treatment conditions that differ according to the degree of inequality.⁷ Table 2.1 provides detailed information on the four treatments: $T25$, $T20-40$, $T15-20-45$ and $T15-55$.

Table 2.1: Experimental treatments

Treatment	Subject type	Nb. of subjects per group	Initial endowment (in ECUs)	Climate budget (in tokens)	Gini coeff.
$T25$	type 3	4	250	25	0
$T20-40$	type 2	3	200	20	0.15
	type 4	1	400	40	
$T15-20-45$	type 1	1	150	15	0.225
	type 2	2	200	20	
	type 5	1	450	45	
$T15-55$	type 1	3	150	15	0.3
	type 6	1	550	55	

In the text, the notion of 'rich' or 'poor' will be based on type 3: types below type 3 (i.e., type 1, type 2) will be poor and types above type 3 (i.e., type 4, type 5, type 6) will be rich.

- In the $T25$ treatment which is our baseline treatment, there is no inequality and the Gini coefficient equals 0. The four group members are endowed with 250 ECUs and a climate budget of 25 tokens. This treatment condition is our baseline and subjects are called type 3 subjects.

⁷For the sake of consistency, endowment inequality and climate budget inequality are equal in each treatment.

- In the *T20-40* treatment, there are two types of players within each group: three poor subjects (we call them type 2 subjects) and one rich subject (type 4 subject). The poor subjects are endowed with 200 ECUS and a climate budget of 20 tokens. The rich subject receives an initial endowment of 400 ECUs and a climate budget of 40 tokens. The Gini coefficient of this distribution of endowment and climate budget is 0.15.
- In the *T15-20-45* treatment, three different types of subjects interact with each other. There is one poor subject of type 1 who gets an initial endowment of 150 ECUs and a climate budget of 15 tokens and two poor subjects corresponding to players of type 2 in the *T20-40* treatment. The rich subject (type 5 subject) has an initial endowment of 450 ECUs and a climate budget of 45 tokens. The Gini coefficient in this treatment condition is equal to 0.225.
- In the *T15-55* treatment, the degree of inequality, as expressed by the Gini coefficient, is the highest (0.3). Each group is composed of three poor who are players of type 1 and of one rich (type 6 subject) who is given an initial endowment of 550 ECUs and a climate budget of 55 tokens.

The six different types of subjects differ according to the size of their endowment and of their climate budget but not regarding the magnitude of the loss they face. As evidenced by Islam and Winkel (2017), when facing climate change, disadvantaged people may differ in terms of their exposure to climate hazards, their susceptibility to damages and their ability to cope with climate change. Here, we consider that subjects within a group are in the same location and therefore have the same exposure to climate hazards (i.e., they face the same potential loss of 150 ECUs). However, subjects types differ in terms of their susceptibility to damages. Poor people are more likely to suffer more intensely from the consequences of climate change. For example, they could live in houses constructed of flimsy materials which could be easily wrecked after a climate disaster. This is illustrated in this experiment by the lower initial endowment of poor subjects. Subjects of type 1 can potentially lose up to their entire endowment in case of a climate event, while for subjects of type 6, a weather event represents at most a loss of 27.3% of their endowment. Furthermore, the capability to cope with climate change also varies according to subjects types. This is depicted by the number of tokens in the climate budget. Indeed, deprived people have less resources to face the climatic upset, and this is why poor subjects receive less

tokens in our experiment.

In each treatment, subjects make the same decision, i.e., deciding on the allocation of their climate budget between measures of mitigation and adaptation. In addition, they are also requested to indicate their beliefs about the total contribution of the three other members of their group. They are rewarded according to the accuracy of their beliefs.⁸ Their gains for each period depend on whether or not the climate event occurs in that period. If there is no climatic event, subjects obtain their initial endowment. In case of a climate event, they get their initial endowment minus the loss (150 ECUs at most) whose size depends on the number of tokens they invested in adaptation. At the end of each period, subjects are informed of the total contribution of their group to mitigation, the resulting probability, the occurrence of the climatic event and their own payoffs.

2.2.3 Inequality and risk preferences, environmental sensitivity

Given the presence of different levels of inequality in this experiment, we elicit subjects' preferences for inequality. As explained by Fehr and Schmidt (1999), individuals may dislike situations with inequitable outcomes. They can feel inequity if they are worse off than others (i.e., disadvantageous inequality), and also if they are better off than others (i.e., advantageous inequality). Therefore, following Blanco et al. (2011), we use an ultimatum game and a modified dictator game to assess, respectively, the aversion to disadvantageous and advantageous inequality of subjects. The ultimatum game is a sequential two-stage game. First, the proposer chooses one way among 11 different proposals to divide 5€ between themselves and the responder (see Appendix 2.B). The offers in the proposals vary from (5€, 0€), (4.5€, 0.5€) to (0€, 5€). Then, the responder indicates from which proposal they accept the offers. If the responder refuses the offer from the proposer, they both get 0€. If the responder accepts it, they get the respective outcomes proposed in the offer. In this game, subjects play the role of both the proposer and the responder. In the modified dictator game, the dictators must choose how much of their initial 5€ (if any) they are willing to sacrifice in order to achieve equal sharing of payoffs between themselves and the receivers (see Appendix 2.B). That is, they must choose between two options: the option X which allows them to always keep the 5€ for themselves and the option Y which contains 11

⁸If their answer is precise, subjects earn 25 additional ECUs. An answer is regarded as precise if it falls within the 20% interval of accepted answers constructed on the basis of subjects type.

different proposals where the payoffs vary from $(0\text{€}, 0\text{€})$, $(0.5\text{€}, 0.5\text{€})$ to $(5\text{€}, 5\text{€})$. At the end of the experiment, subjects are grouped in pairs and are randomly assigned to either the proposer or the responder in the ultimatum game and to either the dictator or the receiver in the dictator game.

We also elicit participants' risk attitude using the method developed by Eckel and Grossman (2002). In this task, subjects are presented with 5 different gambles and have to select only one of them. Each gamble offers a 50% chance of getting the low payoff and a 50% chance of getting the high payoff. The first gamble is a certain gamble (no risk) while the fifth one is the riskiest one (highest expected return and highest standard deviation). Risk-averse subjects are expected to select the gambles with the lowest standard deviations (see Appendix 2.B).

Since the experiment is contextualized, we assess the environmental sensitivity of subjects. Therefore, at the end of the 10 periods of the main game, they must state the frequency, between 1 (never) and 5 (always), with which they undertake 15 different pro-environmental behaviors (see Appendix 2.B). Following Dunlap et al. (2000), subjects also have to complete the New Ecological Paradigm (NEP) scale. It consists of 15 questions on environmental values and attitudes. Subjects indicate whether or not they agree with the statements using a Likert scale from 1 (strongly disagree) to 5 (fully agree) (see Appendix 2.B).⁹

2.2.4 Procedure

A total of 256 subjects participated in 16 sessions (4 sessions per treatment) in January, February and March 2021 at the Laboratory of Experimental Economics in Strasbourg (LEES). Subjects were recruited from a list of experimental subjects maintained at the LEES using the ORSEE software (Greiner, 2015). The experiment was computerized and all sessions followed an identical procedure. Upon arrival, each subject was randomly assigned to a computer. The instructions were read aloud by the experimenter and, before starting, a comprehension questionnaire was administered to check that the rules were well understood. The experiment could start only after all subjects had cleared the control questions.¹⁰ After the ten periods of the main game, subjects completed the survey about their environmental attitudes and the NEP. The last parts of the experiment consisted of the elicitation of risk and inequality preferences. Finally, subjects

⁹We included these two indicators in several tests and estimations. Unsurprisingly, none of them was statistically significant so that we do not report results using them in our analysis.

¹⁰Subjects also played two trial periods before playing the repeated game for ten periods.

answered a post-experimental questionnaire (see Appendix 2.B).

At the end of the experiment, one period from the main game was randomly drawn for actual payment. A random draw was also made to pick the payoff earned by subjects in the risk elicitation task. For the inequality preferences, a random draw was made to determine which of the two tasks would actually be compensated. If the dictator game was selected, then one of the 11 proposals was randomly picked by the computer. The conversion rate was 100 ECUs to 4€ for the main game. Subjects were paid their earnings privately in a separate room at the end of the session. A session lasted 60 minutes on average and the average earnings were 15.30€ (std. dev. = 5.56).

2.3 Predictions

The predictions target the trade-off between mitigation and adaptation. We note w_i ($i \in \{1, 2, 3, 4\}$) the subjects initial endowment, t_i their initial number of tokens, x_i their contribution to mitigation, and $L(x_i)$ the amount of the loss they may incur in each period. Given that a token invested in mitigation decreases the probability of occurrence of a climatic event for the whole group and a token invested in adaptation decreases the size of the loss for the individual only, the subject i 's expected payoff is then given by the expression:

$$E[\Pi_i(x_i)] = w_i - pL(x_i) \tag{2.3}$$

Given the mitigation (2.1) and adaptation (2.2) functions presented in Section 2.2, (2.3) can be rewritten as:

$$E[\Pi_i(x_i)] = w_i - \left(1 - \alpha \sum_{i=1}^4 x_i + \beta \left(\sum_{i=1}^4 x_i\right)^2\right) (1 - \theta(t_i - x_i)) H \tag{2.4}$$

Let us remind that the loss H and the parameters α , β and θ are the same for all subjects but w_i and t_i may vary between subjects and treatments.

We consider, for the sake of simplicity, a group of four symmetric risk-neutral individuals (as in our baseline treatment *T25*). Assuming the contributions of the three other group members as given and equal, subject i maximizes their expected payoff when:

$$\frac{\partial E[\Pi(x_i)]}{\partial x_i} = 0 \Leftrightarrow - \left[\frac{\partial p}{\partial x_i} L(x_i) + \frac{\partial L(x_i)}{\partial x_i} p \right] = 0 \quad (2.5)$$

Given the values of the parameters of the experiment, the amount x_i that satisfies (2.5) is 18.5 (74% of the climate budget in *T25*) and the group investment in mitigation is 74.¹¹ This means that we can expect positive investment in mitigation and this leads us to the following prediction.

Prediction 1 *In the Baseline treatment (T25), individual (and thus group) contributions to mitigation are expected to be positive.*

The same game is repeated for 10 periods. The literature on public good games tells us that we can expect a continuous decay until the last period due to the presence of conditional cooperators (Fischbacher et al., 2001). The same prediction is not evident in our particular environment. Indeed, in our experiment, not investing in mitigation (i.e., not cooperating) is not without consequence for the subject who deviates. An individual who decides to allocate a token to adaptation rather than to mitigation decreases the size of their loss in case of a climate event but also gives up on the possibility to reduce the likelihood of this damage for everyone in the group, including themselves. Therefore, the effect of time in this repeated game is ambiguous and there is no clear-cut prediction regarding repeated periods.

The Warr neutrality theorem states that a redistribution of income does not affect the level of provision of a public good even if there is preference heterogeneity among individuals, as long as “individuals behave as atomistic utility maximizers in the determination of their provision of a single public good, and where this results in an interior solution to their utility maximization problem” (Warr, 1983, p. 208). This theorem relies on three main assumptions: (1) each individual was contributing to the public good before redistribution, (2) they consume at least one private good, and (3) the variations of income are infinitesimal. In 1986, Bergstrom et al. extended this theorem by relaxing the last condition of infinitesimal variations of income and assuming instead that no one loses more income than what they originally gave to the public good. In *T20-40*, *T15-20-45*, and *T15-55*, the distribution of endowments and climate budgets change while the

¹¹As in Isaac and Walker (1998), we introduce non-linearity in the social dilemma. The diminishing marginal returns of the public good (i.e., mitigation) and the constant marginal returns of the private good (i.e., adaptation) result in a non-dominant strategy design with a unique equilibrium for aggregate contributions.

total group endowment and the total number of tokens remain the same as in $T25$. Therefore, we can expect the same level of mitigation regardless of the treatment condition.

Prediction 2 *Group contributions to mitigation are expected to be the same among treatments.*

However, subjects may care not only about their own situation but also about the situation of others, then voluntarily deviating from the optimum in the baseline $T25$. Subjects can display non-traditional preferences such as altruism (Becker, 1974), warm-glow altruism (Andreoni, 1995) or inequality aversion (Fehr and Schmidt, 1999; Ockenfels and Bolton, 2000). In those cases, the literature on public goods has shown that contributions to a public good may be higher than for cases of selfish individuals. This may be particularly important in the three treatments with heterogeneous climate budget ($T20-40$, $T15-20-45$, and $T15-55$). As it has been shown by Buckley and Croson (2006), one may distinguish the effect of altruism and inequality aversion on the decision to contribute to a public good when subjects are heterogeneous according to income. First, if we assume that subjects display altruism in the manner of Becker (1974), where they value their own income and others' income, they will transfer income to others in order to maximize their utility. Buckley and Croson (2006) show that, in this case, individuals with more resources will contribute more to the public good than those with less resources. In our framework, this means that richer people (i.e., with a bigger climate budget) should invest more in mitigation in order to protect the payoff of the poorest.

Prediction 3 *Individuals with a bigger climate budget who are altruist are expected to mitigate more in absolute terms than those with less resources.*

Second, if we assume that subjects display inequality aversion in the manner of Fehr and Schmidt (1999), where they compare their own payoff with the payoff of each member in their group, subjects may want to increase the equality of income between group members. Buckley and Croson (2006) show that individuals with higher income should invest a larger fraction of their income in the public good than those with lower income. This means that given the initial inequality, subjects with higher endowment and bigger climate budget should invest more in mitigation in relative terms than subjects with lower endowment and climate budget.

Prediction 4 *Individuals with a bigger climate budget who are averse to inequality are expected to invest a higher share of their tokens in mitigation.*

Note that this last prediction also means that those subjects are expected to mitigate more in absolute terms than subjects with a smaller climate budget.

2.4 Results

Our variable of interest is the amount of tokens contributed to the mitigation measure. We present the results in four steps. First, we look at group contributions. Then, we compare investment in mitigation between types of subjects within treatment conditions. In a third step, we present the average individual contributions taking into account subjects types between treatment conditions. Finally, we look at the individual choices of contributing to mitigation and we run a series of econometric regressions.

2.4.1 Group contributions

Table 2.2 presents the average group contributions to mitigation in each treatment. The highest contribution to mitigation is observed in *T25* where there is no inequality and amounts to 62.01 tokens. It is slightly lower when there is inequality in *T20-40*, with 61.03 tokens invested on average in mitigation. The lowest average is found in *T15-20-45*, with 56.44 tokens, followed closely by *T15-55*, with an average contribution of 57.06 tokens. Although group contributions are positive, they are statistically lower than 74 (i.e., the optimal group investment in mitigation in *T25*).¹²

Table 2.2: Average group contributions to mitigation (std. dev. in parentheses)

Treatment	Number of observations	Average contribution
<i>T25</i>	16	62.01 (17.77)
<i>T20-40</i>	16	61.03 (19.91)
<i>T15-20-45</i>	16	56.44 (19.89)
<i>T15-55</i>	16	57.06 (22.64)

We find no significant difference in group contributions between treatments according to a two-sided Mann-Whitney rank-sum test taking group averages as the unit of observation.¹³ These results confirm *Prediction 1* and *Prediction 2* which state that contributions to mitigation are

¹²A one-tailed *t*-test indicates that group contributions in each treatment are statistically lower than 74. In *T25*, the p-value is 0.0033, in *T20-40*, it is 0.0075, in *T15-20-45*, it is 0.0005, and in *T15-55*, it is 0.0025.

¹³*T25* vs. *T20-40* (p = 0.8505), *T25* vs. *T15-20-45* (p = 0.4070), *T25* vs. *T15-55* (p = 0.6375), *T20-40* vs. *T15-20-45* (p = 0.5217), *T20-40* vs. *T15-55* (p = 0.7774), *T15-20-45* vs. *T15-55* (p = 0.8802).

positive in the Baseline and that there is no difference between treatments (as predicted by the neutrality theorem).

Result 1 *Group contributions to mitigation are positive in all treatments and not statistically different between treatments.*

Figure 2.1 presents the average group contributions per period. Interestingly, average group contributions remain quite high (although still lower than the group equilibrium in $T25$) and do not decrease over time. This contrasts with results found in classic linear public good games in which we usually observe a decay of contributions in repeated partner designs. However, Hofmeyr et al. (2007) showed that the decay in contributions may be reduced if subjects respect the fair-share rule (we detail the fair-share rule below when looking at within-treatment differences). Our design may also justify the absence of decay. In a classic public good game, it is in the interest of an individual to deviate (i.e., not contributing to the public good) in order to increase their own payoff. In this case however, both measures allow subjects to decrease the expected loss. Therefore, an individual who deviates (i.e., not investing in mitigation) decreases the size of their personal loss at the expense of not reducing the probability of incurring this loss for everyone in the group. This could also explain why we do not observe a decline in contributions over time.

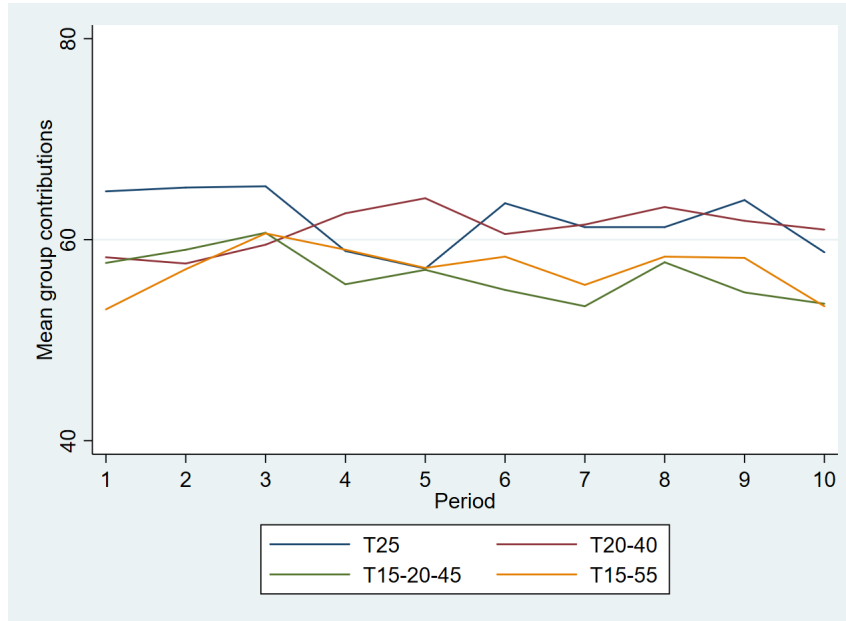
Result 2 *There is no decline in group contributions to mitigation over time.*

2.4.2 Within-treatment comparisons

We then look at the differences between subjects of different types within a treatment condition. Table 2.3 displays the average contribution to mitigation as well as the proportion of the climate budget invested in mitigation by subjects types and per treatment. In $T25$, where each group is exclusively composed of subjects of type 3 with equal endowments (250 ECUs) and climate budgets (25 climate tokens), subjects contribute on average 15.5 tokens to mitigation (which is lower than the theoretical prediction), such that they invest 62.01% of their climate budget.

In $T20-40$, there are three poor subjects of type 2 (endowment of 200 ECUs and 20 climate tokens) and one rich subject of type 4 (endowment of 400 ECUs and 40 climate tokens) in each group. It corresponds to an increase in inequality compared to $T25$. The average contribution of the poor (type 2) to mitigation is 12.04 tokens which represents 60.22% of their climate

Figure 2.1: Average group contributions over time



budget. The rich (type 4) invest 24.9 tokens in mitigation on average, that is 62.25% of their climate budget. The difference between the number of tokens invested in mitigation by poor subjects (type 2) and rich ones (type 4) is statistically significant ($p = 0.0000$).¹⁴ However, there is no significant difference ($p = 0.9627$) between the proportion of climate budget invested in mitigation by the poor and the rich.

The same conclusions hold for *T15-20-45* wherein the inequality of endowment and climate budget is higher than in *T20-40*. In *T15-20-45*, there are three different types of subjects interacting within a group: one poor of type 1 (endowment of 150 ECUs and 15 climate tokens), two poor of type 2 (endowment of 200 ECUs and 20 climate tokens) and one rich of type 5 (endowment of 450 ECUs and 45 climate tokens). Subjects of type 1 invest 7.56 tokens on average (50.42% of their climate budget), subjects of type 2 invest 12.3 tokens (61.52% of their climate budget) and the rich (type 5) invest an average of 24.27 tokens, that is 53.94% of their climate budget. The difference between the number of tokens invested in mitigation by subjects of type 1 and 2 is significant ($p = 0.0078$). It is also the case for the difference between the contribution of subjects of type 1 and 5 ($p = 0.0008$), and between subjects of type 2 and 5 ($p = 0.0007$). Nevertheless, as for the treatment *T20-40*, we find no significant difference between the proportion of tokens

¹⁴Unless specifically noted, we report the significance levels of a two-sided Mann-Whitney (MW) rank-sum test taking individual averages as the unit of observation.

invested in mitigation by types.¹⁵

Table 2.3: Average contributions by subjects types (std. dev. in parentheses)

Treatment	Player type	Number of subjects	Mean contrib.	Prop. of tokens
<i>T25</i>	type 3	64	15.50 (7.51)	62.01 (30.05)
<i>T20-40</i>	type 2	48	12.04 (7)	60.22 (35.02)
	type 4	16	24.9 (11.41)	62.25 (28.52)
<i>T15-20-45</i>	type 1	16	7.56 (6.26)	50.42 (41.75)
	type 2	32	12.30 (6.43)	61.52 (32.15)
	type 5	16	24.27 (14.75)	53.94 (32.78)
<i>T15-55</i>	type 1	48	8.66 (4.86)	57.72 (32.37)
	type 6	16	31.09 (19.52)	56.52 (35.5)

Finally, in treatment *T15-55*, three poor subjects of type 1 (endowment of 150 ECUs and 15 climate tokens) and one rich subject of type 6 (endowment of 550 ECUs and 55 climate tokens) constitute a group. The average contribution of the poor (type 1) is 8.66 tokens which is equivalent to a contribution of 57.72% of their climate budget. The rich (type 6) invest on average 31.09 tokens in mitigation, that is 56.52% of their tokens. Here also, the difference between the poor (type 1) and the rich (type 6) is significant ($p = 0.0000$), but there is no significant difference ($p = 1$) between their investment expressed in proportion of their tokens.¹⁶ These results confirm *Prediction 3* and invalid *Prediction 4*. However, we should be cautious when interpreting them. Concerning *Prediction 3*, the fact that rich subjects contribute more than poor ones could be attributed to social preferences but it could also result from a kind of ‘income effect’, meaning that subjects who get more tokens invest more. Regarding *Prediction 4*, we consider here average values, we are thus not able to see what happens at the individual level and we cannot observe the role of individual preferences. This will be investigated in Subsection 2.4.4.

Result 3 *Within each treatment, rich subjects invest a larger amount of tokens in mitigation than poorer subjects. However, the proportions of climate budget contributed to mitigation are not statistically different between rich and poor subjects.*

These results show that the rich invest more in mitigation than the poor in absolute terms. However, no difference between types is observed in terms of proportion of their tokens. This

¹⁵There is no significant difference between type 1 and type 2 ($p = 0.1644$), nor between type 1 and type 5 ($p = 0.8356$), nor between type 2 and type 5 ($p = 0.5114$).

¹⁶These differences in absolute contributions appear also clearly in Figure 2.A in Appendix 2.A which depicts average contributions over time by subjects type and per treatment.

absence of difference between different types of players is similar to the ‘fair-share’ rule of equal contributions relative to one’s endowment observed in public good games with heterogeneous endowment (Hofmeyr et al., 2007; Keser et al., 2014). In a voluntary contribution mechanism, when there is (weak) asymmetry in the endowment distribution, subjects tend to contribute the same proportion of their endowment which leads to identical level of group contributions as shown in Table 2.2. In our results, this goes a little further since we also observe the absence of difference when we have a strong asymmetry in endowments and in climate budgets (with a Gini coefficient of 0.3). This finding corroborates somehow the theory of reciprocity (Sugden, 1984) stating that if group members contribute to the public good, then the individual has the moral obligation to reciprocate this gesture by investing in the public good. When there is income heterogeneity, individuals will reciprocate following a ‘fair-share’ rule, which in our context means that subjects invest a similar fraction of their tokens.

2.4.3 Between-treatment comparisons

We then look at differences between treatments when we consider specific types of subjects. Indeed subjects of type 1 and 2 are present in two different treatments. This allows us to see if subjects behave differently when facing different levels of inequality. In the first panel of Table 2.4, we compare the decisions made by type 1 and type 2 subjects in two different treatment conditions, i.e., players of type 1 in $T15-55$ and $T15-20-45$, and players of type 2 in $T20-40$ and $T15-20-45$. Table 2.4 reports the results (p-values) of a MW test between the contributions to mitigation (both in level and proportion) of the same types of subjects in the two treatments. The results show no significant difference for players of type 1 regarding the average number of tokens invested in mitigation ($p = 0.4110$), nor regarding the proportion of tokens ($p = 0.4066$). The same conclusions hold for players of type 2. There is no significant difference in the average contributions in absolute terms ($p = 0.8129$), nor in proportion of the climate budget ($p = 0.8206$).

Result 4 *Subjects of the same type do not behave differently in different treatment conditions.*

The second panel of Table 2.4 shows the comparisons between the different types of subjects whatever their treatment conditions. We also report the p-values of MW tests between the number of tokens and the proportion of climate budget invested in mitigation by the different

Table 2.4: Inter-treatments pairwise comparisons (number of obs. in parentheses)

Treatments being compared		Mean contributions	p-value	Proportions of tokens	p-value
type 1:	<i>T15-55</i> (48) vs. <i>T15-20-45</i> (16)	8.66 vs. 7.56	0.4110	57.72 vs. 50.42	0.4066
type 2:	<i>T20-40</i> (48) vs. <i>T15-20-45</i> (32)	12.04 vs. 12.30	0.8129	60.22 vs. 61.52	0.8206

Types being compared		Mean contributions	p-value	Proportions of tokens	p-value
Poor:	type 1 (64) vs. type 2 (80)	8.38 vs. 12.15	0.0000	55.90 vs. 60.74	0.2941
	type 1 (64) vs. type 3 (64)	8.38 vs. 15.50	0.0000	55.90 vs. 62.01	0.1794
	type 2 (80) vs. type 3 (64)	12.15 vs. 15.50	0.0008	60.74 vs. 62.01	0.6604
Rich:	type 3 (64) vs. type 4 (16)	15.50 vs. 24.90	0.0010	62.01 vs. 62.25	0.9520
	type 3 (64) vs. type 5 (16)	15.50 vs. 24.27	0.0079	62.01 vs. 53.94	0.3570
	type 3 (64) vs. type 6 (16)	15.50 vs. 31.09	0.0003	62.01 vs. 56.52	0.4774
	type 4 (16) vs. type 5 (16)	24.90 vs. 24.27	0.8210	62.25 vs. 53.94	0.4737
	type 4 (16) vs. type 6 (16)	24.90 vs. 31.09	0.1998	62.25 vs. 56.52	0.6783
	type 5 (16) vs. type 6 (16)	24.27 vs. 31.09	0.2346	53.94 vs. 56.52	0.8063

types of subjects. This allows us to see if there are differences between poor (type 1 and type 2) and richer (type 4, type 5 and type 6) subjects and subjects in the baseline treatment (type 3). Looking first at poor subjects, we see that subjects of type 1 invest on average 8.38 tokens (whatever the treatment condition), players of type 2 contribute an average of 12.15 tokens (whatever the treatment condition), and players of type 3 invest 15.5 tokens in mitigation. Subjects of type 1 invest less tokens than subjects of type 2 ($p = 0.0000$) and subjects of type 3 ($p = 0.0000$). Subjects of type 2 also contribute less on average than subjects of type 3 ($p = 0.0008$). These results point out an income effect among the poor. When the climate budget increases, subjects invest more in mitigation. However, as for previous results, we do not observe significant difference between these subjects when we look at the contributions as a share of the tokens rather than in absolute terms.¹⁷

The last panel of Table 2.4 focuses on rich subjects. We notice that all types of rich subjects invest, on average, more tokens to mitigation than subjects of type 3. Indeed, subjects of type 3 invest 15.5 tokens which is less than subjects of type 4 who contribute 24.9 tokens ($p = 0.0010$), which is also less than subjects of type 5 who invest 24.27 tokens ($p = 0.0079$), and than subjects of type 6 who allocate 31.09 tokens to mitigation ($p = 0.0003$). However, there is no significant difference in the shares of climate tokens invested in mitigation between the different types of

¹⁷Subjects of type 1 (regardless of the treatment) contribute 55.9% of their climate budget and subjects of type 2 (irrespective of the treatment) invest 60.74% of their tokens in mitigation. This difference is not statistically significant ($p = 0.2941$). The same conclusion holds for subjects of type 1 and subjects of type 3 who contribute 62.01% of their tokens ($p = 0.1794$), and also for subjects of type 2 and subjects of type 3 ($p = 0.6604$).

rich subjects and type 3 subjects.¹⁸ Interestingly, there is no significant difference in the average numbers of tokens invested in mitigation by rich subjects. Average contribution of type 4 subjects is not different from contribution of type 5 subjects ($p = 0.8210$), nor from contribution of type 6 subjects ($p = 0.1998$). We also find no difference between the average number of tokens allocated to mitigation by subjects of type 5 and subjects of type 6 ($p = 0.2346$). Thus, among the rich, the effect of additional tokens on the level of investment in mitigation is nil and we do not observe a similar income effect as for the poor. There is also no significant difference between the share of tokens invested in mitigation by the different types of rich players.¹⁹

Result 5 *There is an income effect for poor subjects, i.e., they invest more in mitigation when their climate budget increases. This is not the case for rich subjects.*

2.4.4 Individual decisions

Finally we run a series of regressions to look at individual decisions. We estimate linear models by ordinary least squares (OLS) with random effects when the dependent variable is the level of contributions to mitigation. When the dependent variable is the proportion of climate budget invested in mitigation, we run fractional probit models with generalized estimating equations (GEE) as developed by Papke and Wooldridge (2008) with random effects. The definition of the variables used in the regressions can be found in Table 2.5. The results of the regressions are displayed in Table 2.6.²⁰

In Table 2.6, the analysis is based on the pooled data over the four treatments. In specifications (1) and (2), we include dummies for each type of subjects by treatment (the reference is type 1 in *T15-55*).²¹ In specifications (3) and (4), we introduce a dummy called *Rich* to distinguish rich subjects (i.e., type 4, type 5 and type 6) from the other types of players and we interact the aversion to inequality (disadvantageous and advantageous) with that dummy. This allows us to see if the aversion to advantageous and disadvantageous inequality affect differently those who are in one or the other position.

¹⁸Subjects of type 3 contribute 62.01% of their tokens while players of type 4 invest 62.25% of theirs. This difference is not statistically significant ($p = 0.9520$). The difference between the proportion of tokens invested in mitigation by subjects of type 3 and subjects of type 5 (who invest 53.94%) is neither significant ($p = 0.3570$), nor is the one by subjects of type 3 and subjects of type 6 (who contribute 56.52%) ($p = 0.4774$).

¹⁹The difference between type 4 and type 5 players is not statistically significant ($p = 0.4737$), nor is the one between players of type 5 and type 6 ($p = 0.8063$), nor between subjects of type 4 and type 6 ($p = 0.6783$).

²⁰The results are robust to whether or not socio-demographic variables are included and available upon request.

²¹The interaction between type and treatment is only necessary for subjects of type 1 and type 2 that are found

Table 2.5: Variables definition

Variables	Definition	Mean (std. dev.)
Rich	1 if subject type is 4, 5 or 6; 0 otherwise	0.19 (0.39)
Nb. of losses	Number of losses incurred over the 10 periods	4.03 (1.78)
Belief	Subject's belief about the total contribution of the 3 other group members	44.92 (16.74)
Period	1 in period 1, 2 in period 2, ..., 10 in period 10	5.50 (2.87)
Socio-demographic variables		
Disadvantageous inequality	From 1 for a person who is not averse, to 11 for a person who is really averse to disadvantageous inequality	5.72 (2.93)
Advantageous inequality	From 1 for a person who is not averse, to 11 for a person who is really averse to advantageous inequality	3.75 (1.78)
Risk-seeking	Answer from an 11-point Likert scale: 0 standing for a careful person, 10 for a person who loves taking risks	5.55 (2.01)
Age	Age of subject	22.10 (3.76)
Female	1 if subject is female; 0 otherwise	0.52 (0.53)
Meselfish	Answer from an 11-point Likert scale: 0 standing for a person who cares about others, 10 for a person who only cares about herself	4.35 (2.33)
Otherselfish	Answer from an 11-point Likert scale: 0 if subject believes people care about others, 10 if subject believes people only care about themselves	6.17 (2.04)
Distrust	1 if subject states that "We must be very careful with people"; 0 otherwise	0.72 (0.45)
Econ-manag.	1 if subject studies economics and management; 0 otherwise	0.42 (0.49)
Earnings	1 if subject states that "They only cared about their own payoff during the third part of the experiment"; 0 otherwise	0.20 (0.40)

We see from column (1) that all the coefficients for the subjects types are positive and statistically significant except for *type 1*T15-20-45*. When comparing these coefficients one to another, the p-values of Wald tests indicate that all coefficients are significantly different at the 1% level except for the comparisons between type 1 in *T15-55* and type 1 in *T15-20-45* ($p = 0.514$), type 2 in *T20-40* and type 2 in *T15-20-45* ($p = 0.397$), type 4 and type 5 ($p = 0.887$), type 4 and type 6 ($p = 0.122$), and finally type 5 and type 6 ($p = 0.129$). These results are in line with the non parametric results presented in the previous subsections, i.e., the same types of players in different treatments do not behave differently, and there is no income effect among the rich. In particular, it corroborates *Results 4* and *5*.

However, when we look at the proportion of tokens invested in mitigation in column (2) of Table

in two treatments. Subjects of type 3, 4, 5 and 6 are only in one treatment each.

Table 2.6: Linear and fractional probit estimations

	Contrib.	Prop.	Contrib.	Prop.
	(1)	(2)	(3)	(4)
type 1*T15-20-45	-0.925 (1.419)	-0.057 (0.086)		
type 2*T20-40	3.458** (1.128)	0.025 (0.055)		
type 2*T15-20-45	4.451*** (1.018)	0.067 (0.05)		
type 3	7.293*** (1.031)	0.058 (0.048)		
type 4	18.005*** (2.274)	0.122 (0.066)		
type 5	17.482*** (3.041)	0.055 (0.075)		
type 6	24.595*** (3.717)	0.087 (0.074)		
Rich			-7.264 (5.464)	-0.380** (0.130)
Nb. of losses	-0.868** (0.271)	-0.027** (0.009)	-0.800** (0.259)	-0.027** (0.008)
Belief	0.111*** (0.016)	0.005*** (0.0007)	0.108*** (0.016)	0.006*** (0.001)
Period	-0.031 (0.049)	-0.003 (0.002)	-0.032 (0.049)	-0.003 (0.002)
Disadvantageous inequality	0.576* (0.268)	0.016 (0.01)	0.082 (0.229)	0.009 (0.010)
Advantageous inequality	0.431* (0.174)	0.012 (0.006)	-0.004 (0.157)	0.002 (0.006)
Rich*disadv. inequality			2.148* (1.085)	0.032 (0.024)
Rich*adv. inequality			2.665*** (0.470)	0.052*** (0.012)
Risk-seeking	-0.539* (0.266)	-0.019* (0.009)	-0.726** (0.246)	-0.019* (0.008)
Age	0.046 (0.125)	9.58e-06 (0.004)	0.050 (0.113)	-0.001 (0.004)
Female	-2.008* (0.872)	-0.090** (0.032)	-3.170*** (0.826)	-0.101*** (0.028)
Meselfish	-0.054 (0.2)	0.0008 (0.007)	0.203 (0.202)	-0.001 (0.006)
Otherselfish	-0.042 (0.218)	-0.004 (0.008)	0.029 (0.234)	0.002 (0.007)
Distrust	-0.446 (1.197)	-0.034 (0.038)	-0.128 (1.123)	-0.034 (0.035)
Econ-manag.	-1.785* (0.895)	-.044 (0.032)	-.761 (0.904)	-0.039 (0.029)
Earnings	-0.128 (1.379)	-0.023 (0.049)	-1.875 (1.263)	-0.052 (0.044)
Constant	6.727 (3.968)	0.525*** (0.142)	14.283*** (3.519)	
N	2560	2560	2560	2560

Standard errors are in parentheses and clustered by individuals in (1), (2), (3).

Average marginal effects are reported in (4). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

2.6, we notice that none of these dummy coefficients is statistically significant.²² The pairwise comparisons of the dummy coefficients indicate that there is no significant difference.²³ Once again, this corroborates the non parametric results which state that there is no difference in the shares of tokens subjects invest in mitigation and therefore confirms *Result 3*.

Among other results, we see that the total number of losses incurred by individuals has a negative effect on investments in mitigation whether it is in absolute terms (column (1)) or in relative terms (column (2)).²⁴ This is an interesting finding since plenty of people already experienced or will experience climate disasters (such as windstorms, floods, etc.) and this result would mean that people would reduce their effort to decrease the probability of such an event in order to protect themselves from its consequences. In a paper on social dilemmas with a risk of loss at the group-level, Blanco et al. (2020) study the use of public insurance (to decrease the probability of the loss) and private insurance (to reduce the magnitude of the individual loss), while also allowing subjects to increase their own payoffs (no insurance). Similarly to our results, the authors find that the more losses people incur, the less they contribute to the public insurance in favor of the private assurance. Miao and Popp (2014) emphasize the fact that people learn and adapt to global warming only after experiencing climate disasters.

The coefficient of *Belief* is positive and statistically significant, suggesting that subjects positively condition their contributions to mitigation to their beliefs. As shown by Fischbacher and Gächter (2010) in public good games, individuals are willing to cooperate in order to induce high beliefs and thus to maintain high contributions to the public good. Furthermore, the time trend is not different from zero, confirming the absence of variation in contributions through periods depicted in Figure 2.1 and in Figure 2.A in Appendix 2.A. This supports *Result 2*. Aversion to advantageous and disadvantageous inequality influence positively contributions to mitigation. We will come back to this when looking at specifications (3) and (4). Subjects who self-identify themselves as risk-takers tend to allocate less tokens to mitigation and thus more to adaptation, as shown by the negative and significant coefficient of *Risk-seeking*. As previously mentioned, both measures induce a reduction in the expected loss: through a decrease in the probability

²²This model has been estimated using OLS rather than GEE because there is a complete separation in the probit regression. Indeed, no player of type 4 invested 0 token in mitigation.

²³The comparisons of *type 1*T15-55* and type 4, and of *type 1*T15-20-45* and type 4, yield a marginally significant difference at the 10% level.

²⁴As a robustness check, we used the occurrence of a climate event in the previous period and we found that it also decreases investments in mitigation in the current period.

(mitigation) or through a decrease in the size of the loss (adaptation). Notwithstanding this and assuming that subjects behave as they claim, they find it riskier to invest less in mitigation than in adaptation. We also witness a gender effect with women tending to mitigate less than men in absolute terms and in proportion of their tokens. A similar effect has been found in Jacob et al. (2021) where contributions are used to decrease the probability of causing a common damage to the environment, and in Blanco et al. (2020).

In the last two specifications of Table 2.6, social preferences, as presented by aversion to disadvantageous and advantageous inequality, matter in the choice to mitigate or to adapt but only for rich subjects. Indeed, the coefficients related to social preferences are only significant when interacted with the dummy *Rich*.²⁵ In specification (3), the coefficients of both interaction terms (related to disadvantageous and advantageous inequality) are positive and statistically significant. It means that the more averse to disadvantageous (resp. advantageous) inequality rich subjects are, the more they mitigate in absolute terms. Surprisingly, the coefficient of the dummy *Rich* is not significant, meaning that a rich player who is not averse to inequality (both disadvantageous and advantageous) do not contribute more tokens to mitigation than a poor subject. This indicates that the difference we observed in the previous subsections between rich and poor in absolute terms is essentially driven by the social preferences of the rich and not by the fact that they have more tokens. We can thus rule out the possibility that rich players respond to an ‘income effect’ and therefore confirm *Result 5* which states that there is no income effect among rich players. Nevertheless, with regard to *Prediction 3*, we are not able to conclude about altruism since we did not specifically measure it. However, we can state that social preferences (as represented by aversion to advantageous and disadvantageous inequality) do explain contributions in absolute terms.

In specification (4), we look at contributions to mitigation as a proportion of the climate budget. The coefficient of the dummy *Rich* is negative and significant when we control for the social preferences of the rich players and the other types of subjects. This implies that rich subjects who are not averse to inequality invest a smaller share of their climate budget than poor players. However, the more averse to advantageous inequality rich players are, the more they contribute to mitigation in relative terms, as evidenced by the positive and significant coefficient of *Rich*adv*.

²⁵We also ran similar regressions exclusively on data over poor players (type 1, type 2), over subjects from the baseline (type 3), and over rich players (type 4, type 5, type 6) and social preferences mattered only in the latter case.

inequality. Unlike specification (3), only aversion to advantageous inequality plays a role in the choice to mitigate or to adapt as a share of the climate budget. Rich players are indeed in a situation of advantageous inequality since they have more tokens and a higher endowment than poor ones. This could justify the fact that they are more sensitive to this kind of inequality.²⁶ These observations confirm *Prediction 4*. On the basis of the above, we present the last result.

Result 6 *Social preferences matter. Aversion to inequality explains the difference between rich and poor in absolute terms and in relative terms.*

2.5 Discussion and conclusion

By means of a modified public good game, this chapter investigates the effect of income inequality on individuals' attitude towards climate change. In the controlled environment of a laboratory, group members decide on the allocation of their climate budget between mitigation (to reduce the probability of a climate disaster for the group) and adaptation (to reduce the size of the damage for themselves). In addition to the climate budget, subjects also receive an endowment to cover the risk of a loss. Between treatments, we manipulate the distribution of climate budgets and endowments within groups so as to increase the degree of inequality.

We find no difference in group contributions between treatments. It means that the degree of inequality does not influence investments in mitigation at the group-level. In the three treatments with inequality (*T20-40*, *T15-20-45*, *T15-55*), subjects manage somehow to cooperate and to coordinate their actions in order to achieve the same level of mitigation as in the baseline treatment (*T25*, no inequality). The results suggest that they actually comply with the 'fair-share' rule. That is, subjects, regardless of their type, invest the same share of their climate budget in mitigation. Poor subjects therefore invest less in absolute terms than rich ones, and the latter make up for the lower contribution of the former.

The fact that there is no 'income effect' among the rich, which is further confirmed by the econometric results, means that rich subjects do not react to the level of inequality per se. Instead, it is their social preferences that matter in their choice to mitigate or to adapt to climate change.

²⁶In a sequential public good game where subjects are paired off, with the first mover deciding whether and how much to contribute and the second mover choosing to contribute the same amount or nothing (so that the latter gets either equal payoff or higher payoff than the first mover), Teyssier (2012) find that social preferences do not matter for the first mover while aversion to advantageous inequality explains the contribution of the second mover.

That is, rich subjects do not mitigate more because they have more resources, but because they are averse to inequality. This echoes the literature related to the role of perceived inequality on attitudes toward redistribution. There is substantial evidence that people’s perception of inequality, rather than the actual levels of inequality, affects their redistributive preferences (Choi, 2019; Hauser and Norton, 2017; Bavetta et al., 2020). Individuals usually misrepresent the actual degree of inequality in society and these misperceptions shape the policy outcomes. When it comes to climate policy, choosing mitigation (i.e., the redistributive policy) over adaptation depends on the (rich) subjects’ degree of inequality aversion, or in other words, on the fact that they view inequality as a ‘bad thing’ or not.

Our repeated game also allows us to assess the impact of losses on the mitigation-adaptation trade-off. Individuals react to the occurrence of climate disasters by adapting more, thus hindering cooperation to mitigate. This is in line with the results of Blanco et al. (2020) who find that subjects who incur a great number of losses invest more in private insurance and less in public insurance. It is somehow similar to regions or cities which witness a flood or a hurricane and respond to it by improvements in their safety. A good example is New Orleans which has built slightly higher levees in response to its recurrent floods (Kates et al., 2006). This result is particularly relevant in the context of climate change, and especially when inequalities exist. Indeed, the climatic upset induces increases in the frequency and the intensity of natural disasters (IPCC, 2021). It is therefore important to find ways to recover cooperation after experiencing bad events in order to protect the most disadvantaged people who suffer disproportionately from climate change.

Bibliography of Chapter 2

- Alvaredo, F., Chancel, L., Piketty, T., Saez, E., and Zucman, G. (2017). Global Inequality Dynamics: New Findings from WID.world. *American Economic Review*, 107(5):404–409.
- Andreoni, J. (1995). Cooperation in Public-Goods Experiments: Kindness or Confusion? *American Economic Review*, 85(4):891–904.
- Andreoni, J. and Petrie, R. (2004). Public goods experiments without confidentiality: a glimpse into fund-raising. *Journal of Public Economics*, 88(7):1605–1623.
- Aubert, D. and Chiroleu-Assouline, M. (2019). Environmental tax reform and income distribution with imperfect heterogeneous labour markets. *European Economic Review*, 116(C):60–82.
- Baland, J.-M., Bardhan, P., Das, S., Mookherjee, D., and Sarkar, R. (2010). The Environmental Impact of Poverty: Evidence from Firewood Collection in Rural Nepal. *Economic Development and Cultural Change*, 59(1):23–61.
- Bavetta, S., Li Donni, P., and Marino, M. (2020). How consistent are perceptions of inequality? *Journal of Economic Psychology*, 78:102267.
- Becker, G. S. (1974). A Theory of Social Interactions. *Journal of Political Economy*, 82(6):1063–1093.
- Bergstrom, T., Blume, L., and Varian, H. (1986). On the private provision of public goods. *Journal of Public Economics*, 29(1):25–49.
- Berthe, A. and Elie, L. (2015). Mechanisms explaining the impact of economic inequality on environmental deterioration. *Ecological Economics*, 116(C):191–200.
- Blanco, E., Dutcher, E. G., and Haller, T. (2020). Social dilemmas with public and private insurance against losses. *Journal of Economic Behavior & Organization*, 180:924–937.
- Blanco, M., Engelmann, D., and Normann, H. T. (2011). A within-subject analysis of other-regarding preferences. *Games and Economic Behavior*, 72(2):321–338.
- Buckley, E. and Croson, R. (2006). Income and wealth heterogeneity in the voluntary provision of linear public goods. *Journal of Public Economics*, 90(4-5):935–955.

- Burton-Chellew, M., May, R., and West, S. (2013). Combined inequality in wealth and risk leads to disaster in the climate change game. *Climatic Change*, 120(4):815–830.
- Cason, T. N., Friesen, L., and Gangadharan, L. (2016). Regulatory performance of audit tournaments and compliance observability. *European Economic Review*, 85:288–306.
- Cassin, L., Melindi-Ghidi, P., and Prieur, F. (2021). The impact of income inequality on public environmental expenditure with green consumerism. Working papers, FAERE - French Association of Environmental and Resource Economists.
- Chan, K., Mestelman, S., Moir, R., and Muller, R. (1999). Heterogeneity and the Voluntary Provision of Public Goods. *Experimental Economics*, 2(1):5–30.
- Chan, K. S., Mestelman, S., Moir, R., and Muller, R. A. (1996). The Voluntary Provision of Public Goods under Varying Income Distributions. *The Canadian Journal of Economics*, 29(1):54.
- Cherry, T., Kroll, S., and Shogren, J. (2005). The impact of endowment heterogeneity and origin on public good contributions: evidence from the lab. *Journal of Economic Behavior & Organization*, 57(3):357–365.
- Choi, G. (2019). Revisiting the redistribution hypothesis with perceived inequality and redistributive preferences. *European Journal of Political Economy*, 58:220–244.
- Dunlap, R., Liere, K., Mertig, A., and Jones, R. (2000). Measuring Endorsement of the New Ecological Paradigm: A Revised NEP Scale. *Journal of Social Issues*, 56:425–442.
- Eckel, C. C. and Grossman, P. J. (2002). Sex differences and statistical stereotyping in attitudes toward financial risk. *Evolution and Human Behavior*, 23(4):281–295.
- Eriksson, C. and Persson, J. (2003). Economic growth, inequality, democratization, and the environment. *Environmental & Resource Economics*, 25(1):1–16.
- Erkal, N., Gangadharan, L., and Nikiforakis, N. (2011). Relative Earnings and Giving in a Real-Effort Experiment. *American Economic Review*, 101(7):3330–3348.
- Fehr, E. and Gächter, S. (2000). Cooperation and punishment in public goods experiments. *American Economic Review*, 90(4):980–994.

- Fehr, E. and Schmidt, K. M. (1999). A Theory of Fairness, Competition, and Cooperation. *The Quarterly Journal of Economics*, 114(3):817–868.
- Fischbacher, U. and Gächter, S. (2010). Social Preferences, Beliefs, and the Dynamics of Free Riding in Public Goods Experiments. *American Economic Review*, 100(1):541–556.
- Fischbacher, U., Gächter, S., and Fehr, E. (2001). Are people conditionally cooperative? evidence from a public goods experiment. *Economics Letters*, 71(3):397–404.
- Frey, B. S. and Meier, S. (2004). Social comparisons and pro-social behavior: Testing "conditional cooperation" in a field experiment. *American Economic Review*, 94(5):1717–1722.
- Gangadharan, L., Nikiforakis, N., and Villeval, M. C. (2017). Normative conflict and the limits of self-governance in heterogeneous populations. *European Economic Review*, 100:143–156.
- Greiner, B. (2015). Subject pool recruitment procedures: organizing experiments with ORSEE. *Journal of the Economic Science Association*, 1(1):114–125.
- Hasson, R., Löfgren, A., and Visser, M. (2010). Climate change in a public goods game: Investment decision in mitigation versus adaptation. *Ecological Economics*, 70(2):331–338.
- Hasson, R., Löfgren, A., and Visser, M. (2012). Treatment Effects of Climate Change Risk on Mitigation and Adaptation Behaviour in an Experimental Setting. *South African Journal of Economics*, 80(3):415–430.
- Hauser, O. P. and Norton, M. I. (2017). (Mis)perceptions of inequality. *Current Opinion in Psychology*, 18:21–25.
- Heerink, N., Mulatu, A., and Bulte, E. (2001). Income inequality and the environment: aggregation bias in environmental kuznets curves. *Ecological Economics*, 38(3):359–367.
- Hofmeyr, A., Burns, J., and Visser, M. (2007). Income inequality, reciprocity and public good provision: an experimental analysis. *The South African Journal of Economics*, 75(3):508–520.
- Isaac, R. M. and Walker, J. M. (1988). Communication and free-riding behavior: the voluntary contribution mechanism. *Economic Inquiry*, 26(4):585–608.
- Isaac, R. M. and Walker, J. M. (1998). Nash as an Organizing Principle in the Voluntary Provision of Public Goods: Experimental Evidence. *Experimental Economics*, 1(3):191–206.

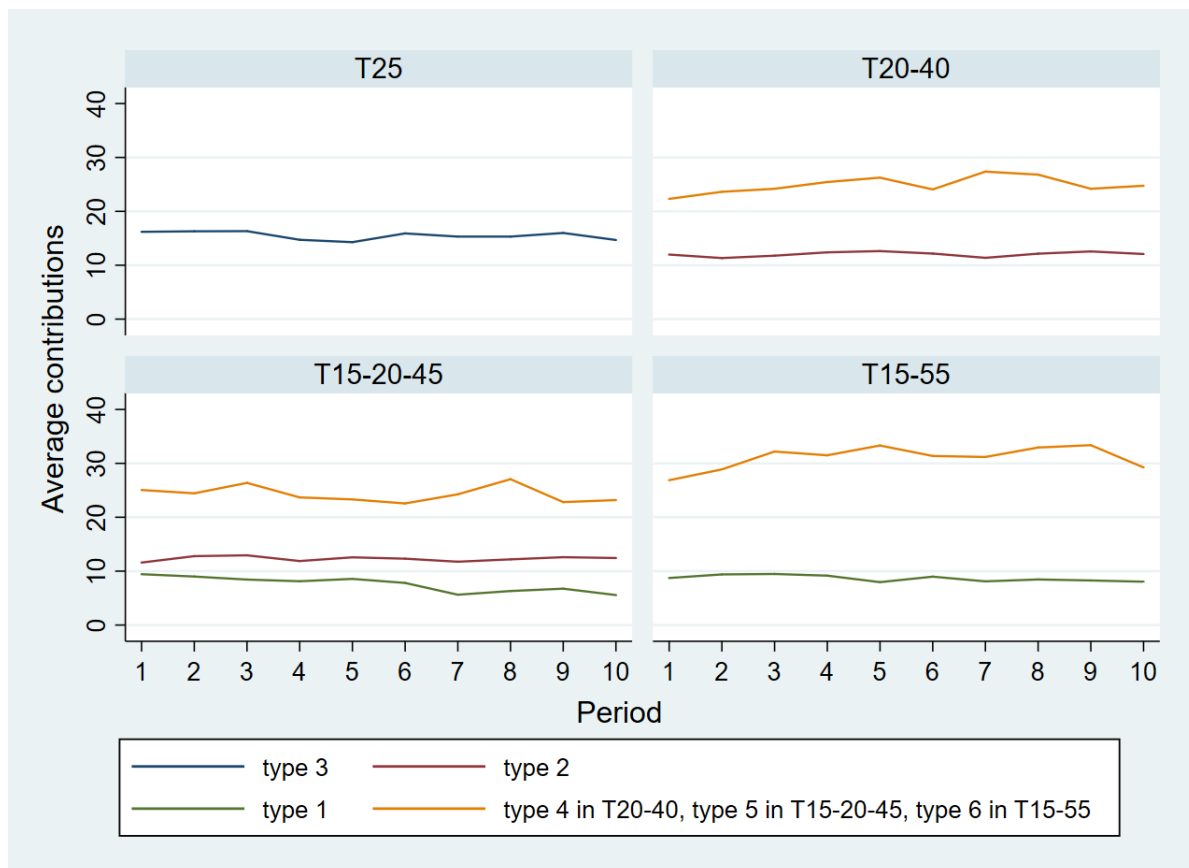
- Islam, N. and Winkel, J. (2017). Climate Change and Social Inequality. UN/DESA Working Paper No. 152.
- Jacob, J., Lambert, E.-A., Lefebvre, M., and Van Driessche, S. (2021). Information disclosure under liability: an experiment on public bads. page 41. BETA Working paper No. 2021-30.
- Jacobs, B. and van der Ploeg, F. (2019). Redistribution and pollution taxes with non-linear Engel curves. *Journal of Environmental Economics and Management*, 95(C):198–226.
- Kates, R. W., Colten, C. E., Laska, S., and Leatherman, S. P. (2006). Reconstruction of New Orleans after Hurricane Katrina: A research perspective. *Proceedings of the National Academy of Sciences*, 103(40):14653–14660.
- Kempf, H. and Rossignol, S. (2007). Is inequality harmful for the environment in a growing economy? *Economics & Politics*, 19(1):53–71.
- Keser, C., Marksttdter, A., Schmidt, M., and Schnitzler, C. (2014). Social Costs of Inequality Heterogeneous Endowments in Public-Good Experiments. Discussion Paper No. 217.
- Ledyard, J. O. (1995). Public Goods: A Survey of Experimental Research. In Kagel, J. H. and Roth, A. E., editors, *The handbook of experimental economics*, pages 111–194. Princeton University Press, Princeton, New Jersey.
- Magnani, E. (2000). The environmental kuznets curve, environmental protection policy and income distribution. *Ecological Economics*, 32(3):431–443.
- Masclet, D., Noussair, C., Tucker, S., and Villeval, M.-C. (2003). Monetary and nonmonetary punishment in the voluntary contributions mechanism. *American Economic Review*, 93(1):366–380.
- Maurice, J., Rouaix, A., and Willinger, M. (2013). Income redistribution and public good provision: an experiment. *International Economic Review*, 54(3):957–975.
- McEvoy, D. M., Haller, T., and Blanco, E. (2022). The Role of Non-Binding Pledges in Social Dilemmas with Mitigation and Adaptation. *Environmental and Resource Economics*, 81(4):685–710.

- Meltzer, A. and Richard, S. F. (1981). A rational theory of the size of government. *Journal of Political Economy*, 89(5):914–27.
- Miao, Q. and Popp, D. (2014). Necessity as the mother of invention: Innovative responses to natural disasters. *Journal of Environmental Economics and Management*, 68(2):280–295.
- Nikiforakis, N., Noussair, C. N., and Wilkening, T. (2012). Normative conflict and feuds: The limits of self-enforcement. *Journal of Public Economics*, 96(9):797–807.
- Ockenfels, A. and Bolton, G. E. (2000). ERC: A Theory of Equity, Reciprocity, and Competition. *American Economic Review*, 90(1):166–193.
- Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Political Economy of Institutions and Decisions. Cambridge University Press.
- Paetzel, F. and Traub, S. (2017). Skewness-adjusted social preferences: Experimental evidence on the relation between inequality, elite behavior, and economic efficiency. *Journal of Behavioral and Experimental Economics*, 68:130–139.
- Papke, L. E. and Wooldridge, J. M. (2008). Panel data methods for fractional response variables with an application to test pass rates. *Journal of Econometrics*, 145(1):121–133.
- Peeters, R. and Vorsatz, M. (2013). Immaterial rewards and sanctions in a voluntary contribution experiment. *Economic Inquiry*, 51(2):1442–1456.
- Reuben, E. and Riedl, A. (2013). Enforcement of contribution norms in public good games with heterogeneous populations. *Games and Economic Behavior*, 77(1):122–137.
- Sugden, R. (1984). Reciprocity: The Supply of Public Goods Through Voluntary Contributions. *The Economic Journal*, 94(376):772–787.
- Tavoni, A., Dannenberg, A., Kallis, G., and Löschel, A. (2011). Inequality, communication, and the avoidance of disastrous climate change in a public goods game. *Proceedings of the National Academy of Sciences*, 108(29):11825–11829.
- Teyssier, S. (2012). Inequity and risk aversion in sequential public good games. *Public Choice*, 151(1-2):91–119.

- Vasconcelos, V. V., Santos, F. C., Pacheco, J. M., and Levin, S. A. (2014). Climate policies under wealth inequality. *Proceedings of the National Academy of Sciences*, 111(6):2212–2216.
- Warr, P. (1983). The private provision of a public good is independent of the distribution of income. *Economics Letters*, 13(2-3):207–211.

Appendix 2.A Average contributions over time per treatment and type of subjects

Figure 2.A: Average contributions over time per treatment and subjects type



Appendix 2.B Instructions

Translated from French to English.

In red, the elements that change in the instructions for treatments other than *T25*.

Thank you for participating in this experiment on the economics of decision making in the context of climate change. In this experiment you will have the opportunity to make money. The amount of your payoff will depend on **your decisions and the decisions of other participants**. Therefore, we ask you to read these instructions carefully since they will help you understand the experiment. All your decisions are **anonymous**. You will never type your name into the computer. You will give your choices to the computer in front of which you are sitting.

From now on, communication is no longer permitted. Please switch off your mobile phone as well. If you have a question, raise your hand and an experimenter will come and answer you in private.

This experiment comprises 3 parts. You have received the instructions for part 1. Each time you finish a part, you will get the instructions for the next one. All participants have the same instructions.

The earnings you can collect by taking part in this experiment are expressed in ECUs (Experimental Currency Units). At the end of each part, your earnings, in ECUs, will be converted in euros according to the conversion rate that applies to the part in question. At the end of the experiment, the gains you will have earned, converted into euros, will be paid to you in cash privately.

PART 1

For this part, the conversion rate is **100 ECUs = 4 €**.

This first part of the experiment comprises 10 periods. During this part, you and 3 other randomly chosen anonymous participants will form a group of 4 persons. This group will remain the same during these 10 periods.

[T20-40, T15-55: Each group will be comprised of 3 poor and 1 rich.]

[T15-20-45: Each group will be comprised of 1 very poor, 2 poor and 1 rich.]

Your status, which has been randomly assigned to you by the computer, will be indicated at the top right of your computer screen at the beginning of that part. It will remain the same throughout this part.

In this part of the experiment, your group represents a small community which must make decisions relating to climate change. In such a context, it is possible that climate events occur in the community (such as rising water leading to floods, extreme heat waves, storms, etc.). If a climatic event occurs it entails a loss of wealth of equal size for each group member [T20-40, T15-55: (poor or rich)] [T15-20-45: (very poor, poor or rich)].

There exist two types of measures that can be taken by every group member in order to face climate change: mitigation measures and adaptation measures.

- The mitigation measures aim at reducing greenhouse gas emissions in the atmosphere such as, for example, sorting and reducing your waste, or even using public transport rather than

your car to move around. These measures serve to decrease the probability of occurrence of climate disasters.

- The adaptation measures seek to reduce the vulnerability of a person to climate change. It consists, for example, of replacing your windows by laminated glass in order to face high winds. These measures serve to decrease the magnitude of climatic events.

Your tasks

At the beginning of each period, you will receive a wealth in ECUs and a climate budget in tokens. The climate budget must be entirely spent and you must decide on its allocation between the measures of mitigation and adaptation.

You receive, in each period, a wealth of 250 ECUs and climate budget of 25 tokens.

T20-40:	If you are poor, you receive, in each period, a wealth of 200 ECUs and a climate budget of 20 tokens. If you are rich, you receive, in each period, a wealth of 400 ECUs and a climate budget of 40 tokens.
T15-20-45:	If you are very poor, you receive, in each period, a wealth of 150 ECUs and a climate budget of 15 tokens. If you are poor, you receive, in each period, a wealth of 200 ECUs and a climate budget of 20 tokens. If you are rich, you receive, in each period, a wealth of 450 ECUs and a climate budget of 45 tokens.
T15-55:	If you are poor, you receive, in each period, a wealth of 150 ECUs and a climate budget of 15 tokens. If you are rich, you receive, in each period, a wealth of 550 ECUs and a climate budget of 55 tokens.

In each period, you must choose how many tokens of your climate budget you want to invest in mitigation (integer) and how many tokens you want to invest in adaptation in order to face a potential climate event that would result in a loss of 150 ECUs for each group member.

Task 1 ⇒ You will indicate how many tokens of your climate budget you want to invest in *mitigation*. The rest of your budget will be invested in *adaptation*.

Mitigation measures

By reducing greenhouse gas emissions, investments in mitigation decrease the probability of a climate event occurring.

Since investments in mitigation reduce the emissions of greenhouse gas in the atmosphere, the

whole community benefits from these investments. In other words, all the group members benefit from the reduction in the probability of occurrence of a climate event whether they invested in mitigation or not.

The probability of occurrence of a climate event decreases **with your investment in mitigation and the investment of the 3 other members of your group in mitigation**. Nevertheless, when deciding, you will not know the choice of the three other group members and the 4 of you will make your decision simultaneously.

In order to help you understand how the probability varies according to the decisions of each group member, you can use the sliders which will appear on your screen. With the upper slider, you can simulate your level of investment in mitigation, and with the lower slider, you can simulate the total level of investment of the 3 other group members in mitigation. The total level of investment of the 3 other group members can vary from 0 token to 75 tokens.

T20-40:	can vary from 0 token to 80 tokens if you are poor; can vary from 0 token to 60 tokens if you are rich.
T15-20-45:	can vary from 0 token to 85 tokens if you are very poor; can vary from 0 token to 80 tokens if you are poor; can vary from 0 token to 55 tokens if you are rich.
T15-55:	can vary from 0 token to 85 tokens if you are poor; can vary from 0 token to 45 tokens if you are rich.

Let us take 2 examples at random:

Example 1: Suppose that the 3 other group members invested in total 44 tokens in mitigation. If you decide to invest 11 tokens in mitigation, the probability of occurrence of the climate event will then be of 40.2%. Thus, there will be a 40.2% chance that the climate event occurs in your group.

Example 2: Suppose that the 3 other group members invested in total 21 tokens in mitigation. If you decide to invest 7 tokens in mitigation, the probability of occurrence of the climate event will then be of 63.9%. Thus, there will be a 63.9% chance that the climate event occurs in your group.

Note that if no one invests in mitigation, the probability of a climate event occurring is equal to 100% (it occurs with certainty); on the contrary, if the 4 group members invest all of their tokens in mitigation, the probability decreases down to 25%.

Adaptation measures

Investments in adaptation serve to reduce the severity of the climate event **for yourself only**. In other words, by investing in adaptation, you can decrease the size of the loss of wealth you would incur if a climate event occurs.

Unlike mitigation measures, adaptation measures benefit only the person who makes the investments. Therefore, the size of the loss of wealth you will incur if a climate event occurs in your group **decreases only with your investment** in adaptation.

In order to help you understand how the size of the loss varies according to your decisions, you can refer to the adaptation table.

T20-40, T15-55:	can refer to the left part of the adaptation table if you are poor; can refer to the right part of the adaptation table if you are rich.
T15-20-45:	can refer to the left part of the adaptation table if you are very poor; can refer to the middle part of the adaptation table if you are poor; can refer to the right part of the adaptation table if you are rich.

[T20-40, T15-20-45, T15-55: NB: all tables are identical but depend on the number of tokens you have.]

Let us take 2 examples at random:

Example 1: you decide to invest 6 tokens of your climate budget in adaptation. If the climate event occurs, the loss of wealth you will bear will be of 139.2 ECUs.

Example 2: you decide to invest 14 tokens of your climate budget in adaptation. If the climate event occurs, the loss of wealth you will bear will be of 124.9 ECUs.

Task 2 \Rightarrow In each period, once you will have decided on the allocation of your climate budget, you will have to indicate what you think **the total investment in mitigation of the 3 other members of your group** will be for that period. If your answer is precise, you will receive 25 additional ECUs.

- You will indicate an integer between 0 and 75 tokens (the maximal number of tokens that the 3 other members of your group can invest in mitigation). If your answer is exact or does not depart from the actual one by more than 7, you will earn 25 additional ECUs. If your answer departs from the actual one by more than 7, you will earn nothing.

T20-40:	If you are poor: You will indicate an integer between 0 and 80 tokens (the maximal number of tokens that the 3 other members of your group can invest in mitigation). If your answer is exact or does not depart from the actual one by more than 7, you will earn 25 additional ECUs. If your answer departs from the actual one by more than 7, you will earn nothing.
	If you are rich: You will indicate an integer between 0 and 60 tokens (the maximal number of tokens that the 3 other members of your group can invest in mitigation). If your answer is exact or does not depart from the actual one by more than 5, you will earn 25 additional ECUs. If your answer departs from the actual one by more than 5, you will earn nothing.
T15-20-45:	If you are very poor: You will indicate an integer between 0 and 85 tokens (the maximal number of tokens that the 3 other members of your group can invest in mitigation). If your answer is exact or does not depart from the actual one by more than 8, you will earn 25 additional ECUs. If your answer departs from the actual one by more than 8, you will earn nothing.
	If you are poor: You will indicate an integer between 0 and 80 tokens (the maximal number of tokens that the 3 other members of your group can invest in mitigation). If your answer is exact or does not depart from the actual one by more than 7, you will earn 25 additional ECUs. If your answer departs from the actual one by more than 7, you will earn nothing.
	If you are rich: You will indicate an integer between 0 and 55 tokens (the maximal number of tokens that the 3 other members of your group can invest in mitigation). If your answer is exact or does not depart from the actual one by more than 5, you will earn 25 additional ECUs. If your answer departs from the actual one by more than 5, you will earn nothing.
T15-55:	If you are poor: You will indicate an integer between 0 and 85 tokens (the maximal number of tokens that the 3 other members of your group can invest in mitigation). If your answer is exact or does not depart from the actual one by more than 8, you will earn 25 additional ECUs. If your answer departs from the actual one by more than 8, you will earn nothing.
	If you are rich: You will indicate an integer between 0 and 45 tokens (the maximal number of tokens that the 3 other members of your group can invest in mitigation). If your answer is exact or does not depart from the actual one by more than 4, you will earn 25 additional ECUs. If your answer departs from the actual one by more than 4, you will earn nothing.

Once each member will have estimated the total investment in mitigation of the 3 other group members, the computer will randomly determine, according to the probability resulting from the decisions of the 4 group members, whether or not the climate event occurs.

The periods are independent from each other, meaning that if a climate event occurs in a period, it does not affect the probability of occurrence in the next ones.

Your gains

Your gains, in each period, are the sum of two amounts (gain for task 1 and gain for task 2) and depend on the occurrence of the climatic event:

The climate event does not occur	250 ECUs (your wealth) + gain for task 2
The climate event occurs	250 ECUs (your wealth) - size of the loss (see adaptation table) + gain for task 2

T20-40:	The climate event does not occur	If you are poor	200 ECUs (your wealth) + gain for task 2
		If you are rich	400 ECUs (your wealth) + gain for task 2
	The climate event occurs	If you are poor	200 ECUs (your wealth) - size of the loss (see adaptation table) + gain for task 2
		If you are rich	400 ECUs (your wealth) - size of the loss (see adaptation table) + gain for task 2
T15-20-45:	The climate event does not occur	If you are very poor	150 ECUs (your wealth) + gain for task 2
		If you are poor	200 ECUs (your wealth) + gain for task 2
		If you are rich	450 ECUs (your wealth) + gain for task 2
	The climate event occurs	If you are very poor	150 ECUs (your wealth) - size of the loss (see adaptation table) + gain for task 2
		If you are poor	200 ECUs (your wealth) - size of the loss (see adaptation table) + gain for task 2
		If you are rich	450 ECUs (your wealth) - size of the loss (see adaptation table) + gain for task 2
T15-55:	The climate event does not occur	If you are poor	150 ECUs (your wealth) + gain for task 2
		If you are rich	550 ECUs (your wealth) + gain for task 2
	The climate event occurs	If you are poor	150 ECUs (your wealth) - size of the loss (see adaptation table) + gain for task 2
		If you are rich	550 ECUs (your wealth) - size of the loss (see adaptation table) + gain for task 2

Let us take 1 example **by status** at random to explain the gains for task 1:

You have a climate budget of 25 tokens. You decide to invest 16 tokens in mitigation and 9 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 133.9 ECUs. If your group is not hit by a climate event, your gains for task 1 amount, for that period, to 250 ECUs.

If your group is hit by a climate event, your gains for task 1 amount, for that period, to $250 - 133.9 = 116.1$ ECUs.

T20-40:	<p>If you are poor: You have a climate budget of 20 tokens. You decide to invest 7 tokens in mitigation and 13 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 126.7 ECUs.</p> <p>If your group is not hit by a climate event, your gains for task 1 amount, for that period, to 200 ECUs.</p> <p>If your group is hit by a climate event, your gains for task 1 amount, for that period, to $200 - 126.7 = 73.3$ ECUs.</p>
	<p>If you are rich: You have a climate budget of 40 tokens. You decide to invest 12 tokens in mitigation and 28 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 99.8 ECUs.</p> <p>If your group is not hit by a climate event, your gains for task 1 amount, for that period, to 400 ECUs.</p> <p>If your group is hit by a climate event, your gains for task 1 amount, for that period, to $400 - 99.8 = 300.2$ ECUs.</p>
T15-20-45:	<p>If you are very poor: You have a climate budget of 15 tokens. You decide to invest 2 tokens in mitigation and 13 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 126.7 ECUs.</p> <p>If your group is not hit by a climate event, your gains for task 1 amount, for that period, to 150 ECUs.</p> <p>If your group is hit by a climate event, your gains for task 1 amount, for that period, to $150 - 126.7 = 23.3$ ECUs.</p>
	<p>If you are poor: You have a climate budget of 20 tokens. You decide to invest 9 tokens in mitigation and 11 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 130.3 ECUs.</p> <p>If your group is not hit by a climate event, your gains for task 1 amount, for that period, to 200 ECUs.</p> <p>If your group is hit by a climate event, your gains for task 1 amount, for that period, to $200 - 130.3 = 69.7$ ECUs.</p>
	<p>If you are rich: You have a climate budget of 45 tokens. You decide to invest 17 tokens in mitigation and 28 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 99.8 ECUs.</p> <p>If your group is not hit by a climate event, your gains for task 1 amount, for that period, to 450 ECUs.</p> <p>If your group is hit by a climate event, your gains for task 1 amount, for that period, to $450 - 99.8 = 350.2$ ECUs.</p>
T15-55:	<p>If you are poor: You have a climate budget of 15 tokens. You decide to invest 2 tokens in mitigation and 13 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 126.7 ECUs.</p> <p>If your group is not hit by a climate event, your gains for task 1 amount, for that period, to 150 ECUs.</p> <p>If your group is hit by a climate event, your gains for task 1 amount, for that period, to $150 - 126.7 = 23.3$ ECUs.</p>
	<p>If you are rich: You have a climate budget of 55 tokens. You decide to invest 27 tokens in mitigation and 28 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 99.8 ECUs.</p> <p>If your group is not hit by a climate event, your gains for task 1 amount, for that period, to 550 ECUs.</p> <p>If your group is hit by a climate event, your gains for task 1 amount, for that period, to $550 - 99.8 = 450.2$ ECUs.</p>

At the end of each period, you will be informed of the total investment of your group in mitigation, the resulting probability, the occurrence of the loss and your gains for that period.

At the end of the experiment, only 1 in 10 periods will actually be paid according to the conversion rate in euros. One participant will randomly draw a period in order to calculate the earnings for this first part. Each period has the same probability of being selected.

Before starting this part, you will have to complete a questionnaire designed to verify that you understood the instructions. Once completed, you will play for 2 periods with the computer in order to familiarize you with the functioning of this part. Then, you will play in your group for 10 periods.

Figure 2.B: Adaptation table in T25

Adaptation table

Amount of the loss (in ECUs) that you will have to bear if a climatic event occurs according to your investment in adaptation

	Amount of the loss (in ECUs)
0	150.0
1	148.2
2	146.4
3	144.6
4	142.8
5	141.0
6	139.2
7	137.4
8	135.6
9	133.9
10	132.1
11	130.3
12	128.5
13	126.7
14	124.9
15	123.1
16	121.3
17	119.5
18	117.7
19	115.9
20	114.1
21	112.3
22	110.5
23	108.7
24	106.9
25	105.2

Your investment in adaptation

Values are rounded to 0.1.

Figure 2.C: Adaptation table in T15-55

Adaptation table
Amount of the loss (in ECUs) that you will have to bear if a climatic event occurs according to your investment in adaptation

POOR		RICH	
	Amount of the loss (in ECUs)		Amount of the loss (in ECUs)
0	150.0	0	150.0
1	148.2	1	148.2
2	146.4	2	146.4
3	144.6	3	144.6
4	142.8	4	142.8
5	141.0	5	141.0
6	139.2	6	139.2
7	137.4	7	137.4
8	135.6	8	135.6
9	133.9	9	133.9
10	132.1	10	132.1
11	130.3	11	130.3
12	128.5	12	128.5
13	126.7	13	126.7
14	124.9	14	124.9
15	123.1	15	123.1
		16	121.3
		17	119.5
		18	117.7
		19	115.9
		20	114.1
		21	112.3
		22	110.5
		23	108.7
		24	106.9
		25	105.2
		26	103.4
		27	101.6
		28	99.8
		29	98.0
		30	96.2
		31	94.4
		32	92.6
		33	90.8
		34	89.0
		35	87.2
		36	85.4
		37	83.6
		38	81.8
		39	80.0
		40	78.2
		41	76.4
		42	74.7
		43	72.9
		44	71.1
		45	69.3
		46	67.5
		47	65.7
		48	63.9
		49	62.1
		50	60.3
		51	58.5
		52	56.7
		53	54.9
		54	53.1
		55	51.3

Values are rounded to 0.1.

ENVIRONMENTAL QUESTIONNAIRES

For that part, you will have to complete two questionnaires. Take your time to respond to the questions honestly and precisely. There is no good or wrong answer. We remind you that all your answers are anonymous and will be used only by the researchers involved in this project.

Answer by stating the frequency with which (never, rarely, sometimes, often, always):

1. You take shorter showers to save water.
2. You turn off the tap while brushing your teeth.

3. You only do your laundry with full loads.
4. You only run the dishwasher with full loads.
5. When you go to the toilet and there are two flush buttons, you use the small one.
6. You sort glass, plastic, paper, and metal.
7. You travel by foot, or use public transport/a bike to go to work, to go to school, to go shopping, etc.
8. You buy the organic alternative of a product when it is available.
9. You buy a product instead of another one because there is less packaging.
10. You buy a product instead of another one because it is produced locally.
11. You turn off the lights when you leave a room.
12. You use reusable bags when you do your grocery shopping.
13. You buy second-hand goods.
14. You disconnect devices in sleep mode.
15. You put on more clothes instead of increasing the heat when it gets cold.

Indicate if you agree or disagree with the following statements (strongly disagree, disagree, do not know, agree, strongly agree):

1. We are approaching the limit of the number of people the earth can support.
2. Humans have the right to modify the natural environment to suit their needs.
3. When humans interfere with nature it often produces disastrous consequences.
4. Human ingenuity will insure that we do NOT make the earth unlivable.
5. Humans are severely abusing the environment.
6. The earth has plenty of natural resources if we just learn how to develop them.
7. Plants and animals have as much right as humans to exist.
8. The balance of nature is strong enough to cope with impacts of modern industrial nations.
9. Despite our special abilities humans are still subject to the laws of nature.
10. The so-called "ecological crisis" facing humankind has been greatly exaggerated.
11. The earth is like a spaceship with very limited room and resources.
12. Humans were meant to rule over the rest of nature.
13. The balance of nature is very delicate and easily upset.
14. Humans will eventually learn enough about how nature works to be able to control it.

15. If things continue on their present course, we will soon experience a major ecological catastrophe.

PART 2

In this part, you will have only one decision to make. You will have to choose **one** gamble from 5 different gambles. Your earnings for this part will depend on the outcome of the gamble. For each gamble, there are 2 possible earnings: earnings from situation A and earnings from situation B. Each situation has a 50% chance of happening.

In order to determine your earnings for this part, the computer will toss a coin virtually. If it is heads, situation A will happen and if it is tails, situation B will happen. Your earnings will correspond to the earnings of the winning situation of the gamble you will have chosen.

[Displayed on the screen:]

Gamble	Situation A (50%)	Situation B (50%)
1	3€	3€
2	4€	2.5€
3	5€	2€
4	6€	1.5€
5	7€	1€

PART 3

For this part, there are two tasks. Only one of these 2 tasks will actually be paid at the end of the experiment. One participant will randomly draw a task in order to determine your gain for that third part. Each task has the same probability of being selected.

Task 1

For that task, there are two roles: player A and player B.

Player A must choose one way, among 11 propositions, to distribute 5€ between themselves and player B.

Player B knows that player A must make this choice and can either accept the distribution chosen by player A or refuse it. If player B accepts the proposition, the players receive the amounts of money stated in the proposition. If player B refuses, the players receive nothing (0€).

Your role (player A or player B) will be randomly determined by the computer at the end of the experiment.

Meanwhile, you will take your decisions **first as player A, then as player B**.

- *As player A*, you must choose how you want to distribute 5 € between yourself and player B, among the 11 propositions that will appear on your screen. From proposition 1 to 11, the gain of player A decreases from 5 € to 0 €, 0.5 € by 0.5 €, and the gain of player B increases from 0 € to 5 €, 0.5 € by 0.5 €.

→ You will indicate the number of the proposition (between 1 and 11) that you chose.

- *As player B*, you must decide, for each of the 11 propositions, if you accept it or refuse it.

→ You will indicate the number of the proposition until which you want to refuse the propositions and beyond which you want to accept the propositions.

Example: if you indicate 2, it means that until proposition 2, you refuse the propositions and you accept the propositions from proposition 3. Once you accepted a proposition, you cannot refuse the following ones.

At the end of the experiment, you will be paired with another participant and the computer will determine your respective roles.

Your gains will depend on the role assigned by the computer:

- *If you are player A*, you will earn the amount stated in the proposition you have chosen provided that player B, with whom you will be paired, accepted your proposition beforehand. Otherwise, both of you will earn 0 €.
- *If you are player B*, you will earn the amount stated in the proposition chosen by player A, with whom you will be paired, provided that you accepted that proposition beforehand. Otherwise, both of you will earn 0 €.

Task 2

For that task, there are two roles: player A and player B.

Player A must choose between two options to distribute 5 € between themselves and player B for each of the 11 propositions.

Player B knows that player A must take these decisions and can do nothing but accept them.

Your role (player A or player B) will be randomly determined by the computer at the end of the experiment.

Meanwhile, you will take your decisions **as player A**.

The 11 propositions will appear on your screen. For each one of them, you must choose between option X and option Y. If you choose option X, you keep the 5 € for yourself and player B receives nothing (0 €). If you choose option Y, you and player B receive the same amount (this amount increases by 0.5 € from a proposition to the next one).

→ You will indicate the number (between 1 and 11) of the proposition until which you prefer option X and beyond which you prefer option Y.

Example: if you indicate 2, it means that until proposition 2, you prefer option X and from proposition 3, you prefer option Y. Once you chose option Y for a proposition, you cannot choose option X for the following ones.

At the end of the experiment, you will be paired with another participant and the computer will determine your respective roles.

Your gains will depend on the role assigned by the computer **and** on the proposition which will have been randomly selected by the computer:

- *If you are player A*, you will earn the amount that you chose for player A for the proposition selected by the computer.
- *If you are player B*, you will earn the amount that player A, with whom you will be paired, chose for player B for the proposition selected by the computer.

POST-EXPERIMENTAL QUESTIONNAIRE

1. Your age:

2. Your sex: *Male; Female; Other*

3. Your degree: *Bachelor; Master; PhD*

4. Your field of study: *Law; Economics and Management; Literature and Languages; Hard sciences; Psychology and Sociology; Political science; Other (please specify)*

5. In everyday life, do you think that you are a person who rather takes risks or a rather careful person? Please indicate on a scale of 0 to 10 where do you think you stand; 0 standing for a very careful person and 10 for a person who loves taking risks. *0; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10*

6. In everyday life, do you think that you try to help other people or that you only care about your own concerns? Please indicate on a scale of 0 to 10 where do you think you stand; 0 standing for a person who loves helping others and 10 for a person who acts in their own interest. *0; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10*

7. In everyday life, do you think that people try to help others or that they only care about their own concerns? Please indicate on a scale of 0 to 10 where do you position other people; 0 standing for a person who loves helping others and 10 for a person who acts in their own interest. *0; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10*

8. Generally speaking, do you think that we can trust most people or that we must be very careful with people? *We can trust most people; We must be very careful with people*

9. During the third part of the experiment, which information did guide your decisions? *Only your payoff; Your payoff and others' payoff such that they do not have less than you; Your payoff and others' payoff such that they do not have more than you; Your payoff and others' payoff such that they have no more and no less than you*

10. Which criteria did guide your decisions during the experiment?

11. In your opinion, what was the objective of this experiment?

Chapter 3

Risk and ambiguity preferences in the climate change context

Sarah Van Driessche, Kene Boun My & Marielle Brunette

In this chapter, we analyze the role of risk and ambiguity preferences on the decision to mitigate or to adapt to climate change. We run an experiment where every group of four subjects is exposed to a climate risk that can entail a loss for each group member. Subjects must decide on the allocation of their resources between mitigation policies that allow them to decrease the probability of a climate disaster occurring for the group, and adaptation policies that allow them to reduce the magnitude of that disaster for themselves only. In a first treatment, subjects perfectly know the probability of occurrence of the climate event. We introduce ambiguity with regard to that probability in a second treatment, and in a third treatment, subjects have the possibility to pay to obtain information allowing them to eliminate ambiguity. The results show that the introduction of ambiguity and the possibility to obtain information have no impact on average contributions. However, individual decisions to mitigate or to adapt are affected by preferences toward risk and ambiguity. Ambiguity preferences also explain the intensity of the willingness to pay to obtain information.

Contents

3.1	Introduction	121
3.2	Experimental design	125
3.2.1	Main game	125
3.2.2	Treatments	126
3.2.3	Subjects' preferences	130
3.2.4	Procedure	131
3.3	Results	132
3.3.1	Average contributions	133
3.3.2	Individual decisions	138
3.4	Discussion and conclusion	145
	Bibliography of Chapter 3	146
	Appendices of Chapter 3	151
3.A	Comparison of Classic and Environment subjects	151
3.B	Instructions	152

3.1 Introduction

The last report of the IPCC¹ (2021) emphasizes the urgent need to limit climate change. Societies must strengthen their mitigation efforts, just as they need to become more resilient by adopting effective adaptation policies. Dealing with climate change also comes with the uncertainties that surround this global issue which make it even more challenging (Etner et al., 2020; Boucher and Bramoullé, 2010; Bramoullé and Treich, 2009; Raihani and Aitken, 2011). Societal choices and actions implemented to tackle climate change in the immediate future will determine the next state of the world. The five SSP² scenarios of the IPCC are specifically designed to describe different plausible evolutions of the future society. Based on diverse socio-economic hypotheses and on different levels of greenhouse gas (GHG) emissions, they represent uncertain future situations. In this sense, these scenarios constitute a common basis to make decisions but are still ambiguous with regard to the likelihood of each one of them.³ Individuals are therefore not aware of the future climate conditions even though they need to address climate change right now through the implementation of mitigation and adaptation policies. This also raises the question of investments in more and better information in order to allay the uncertainties related to climate change (Morath, 2010; Kuusela and Laiho, 2020; Ingham et al., 2007).

In this ambiguous context, one may wonder what type of effort individuals are willing to make to cope with global warming. We consider that individuals may undertake two types of actions: mitigation or adaptation practices.⁴ Mitigation policies aim at curtailing the emissions of greenhouse gas in the atmosphere to lower the probability of bad climate states occurring (e.g., use of cleaner energy). Adaptation policies, however, serve to decrease the vulnerability of a person to the adverse consequences of climate change (e.g., installation of a drain system around one's house).^{5,6} It becomes apparent that mitigation can be compared to a global public good wherein

¹IPCC: Intergovernmental Panel of experts on Climate Change.

²SSP: Shared Socio-economic Pathways.

³We refer to ambiguity as unknown probabilities and use the following definition: "ambiguity is uncertainty about probability, created by missing information that is relevant and could be known" (Camerer and Weber, 1992, p. 330). This is actually what Knight (1921) called 'uncertainty'.

⁴There has been a vast debate in the literature on the kind of relationship that exists between mitigation and adaptation strategies (i.e., substitutes or complements) (see e.g., Kane and Shogren, 2000; Tol, 2005; Ingham et al., 2013; Greenhill et al., 2018). However, it is now unequivocal that an optimal climate policy should include a mix of both strategies (Parry, 2007).

⁵Mitigation and adaptation refer to the concepts of Ehrlich and Becker (1972), respectively self-protection which is a decrease in the probability of a loss and self-insurance which is a reduction in the magnitude of a loss.

⁶In this chapter, we do not consider potential side effects of adaptation, such as maladaptation (e.g., installing an air conditioning system and therefore using more energy) (Scheraga and Grambsch, 1998).

each individual faces a cost to reduce GHG emissions while everyone can benefit from this reduction regardless of one's own contribution (Hasson et al., 2010, 2012). The trade-off between mitigation and adaptation therefore translates into a collective action problem. In addition to the conflicting interests between what is individually rational and what is socially optimal, risk and ambiguity preferences of individuals may alter this choice. It is likely that decisions in terms of mitigation and adaptation change according to individual preferences.

In this chapter, we propose to analyse how risk and ambiguity preferences affect the decisions of individuals to mitigate or to adapt to climate change. For that purpose, we implement an original contextualized experiment with students. The experimental design supposes a climatic risk that can entail a loss (Hasson et al., 2010, 2012; Lefebvre and Van Driessche, 2022). In a first step, subjects are members of a group and they have to decide how much to invest in mitigation in order to reduce the probability of occurrence of the climate disaster for the whole group, and how much to allocate to adaptation in order to reduce the severity of the loss for themselves only. In the first treatment (risk), subjects are in a risky situation. They perfectly know the probability of a climatic event occurring. In the second treatment (ambiguity), we introduce ambiguity with regard to the probability of occurrence of the climate event, so that subjects do not know in which state of nature they are. We also have a third treatment (information acquisition) in which we question subjects about their willingness to pay to obtain information, allowing them to go from an ambiguous context to a risky one. In a second step, subjects take individual decisions, which gives us a measure of their risk and ambiguity preferences.

Our chapter is closely related to several other studies. Hasson et al. (2010, 2012) are the first to model the mitigation-adaptation trade-off as a public good experiment.⁷ In a first paper, Hasson et al. (2010) study the impact of changing the vulnerability of subjects (i.e., the size of the climate event). They do not find any difference between the low-vulnerability and the high-vulnerability treatments. They explain this result by the role of trust (i.e., beliefs). In another paper, Hasson et al. (2012) compare a deterministic model (the climate hazard occurs with certainty) and a stochastic one (there is a risk of a climate event occurring). The results indicate that there is no difference between the two models in terms of mitigation and that the level of cooperation is rather low. Lefebvre and Van Driessche (2022) experimentally examine the effects of income

⁷Nevertheless, our experimental design differs from theirs in the sense that the authors consider a one-shot public good game with discrete choice. That is, subjects could choose to invest their whole endowment in either mitigation or adaptation but not in both measures at the same time.

inequality on the mitigation-adaptation trade-off. They find out that group contributions are not affected by the degree of inequality. McEvoy et al. (2022) look at the effect of non-binding pledges when subjects only have the possibility to mitigate, and when they can both mitigate and adapt. Their results suggest that pledges increase mitigation contributions only when both climate policies are available. Blanco et al. (2020) also study social dilemmas but in a wider context than climate change. Subjects are given three possibilities to face potential losses at the group-level: public insurance (reduction in the group probability), private insurance (reduction in the individual size of the loss), and no insurance (increase in the individual payoff). They investigate the impact of varying the size of the loss and find that investments in public insurance decrease as this size decreases. Keser and Montmarquette (2008) examine the behavior of group members who can collectively contribute to reduce the probability of a common loss. They show that introducing ambiguity has a negative impact on the level of voluntary contributions.

This chapter is also related to another strand of the literature, namely public good games with uncertainty. There is no clear picture that emerges from that literature. Some experiments have focused on introducing uncertainty about the marginal per capita return (see e.g., Fisher et al., 1995; Boulu-Reshef et al., 2017; Théroude and Zylbersztejn, 2020; Fischbacher et al., 2014; Björk et al., 2016; Levati et al., 2009), while others have looked at the effect of introducing uncertainty about actually receiving the benefits from the public good (see e.g., Gangadharan and Nemes, 2009; Dickinson, 1998; Levati and Morone, 2013). Boulu-Reshef et al. (2017), Théroude and Zylbersztejn (2020), Björk et al. (2016), and Fisher et al. (1995) find no effect of uncertainty on the level of contributions. However, Gangadharan and Nemes (2009), Fischbacher et al. (2014), and Levati et al. (2009) show evidence of a negative effect on cooperation. Levati and Morone (2013) state that this negative impact is due to the payoff parameterization. Other papers have looked at the effect of uncertainty in threshold public good games. In this kind of game, the provision of the public good must attain a certain level in order to avoid a collective loss. Barrett and Dannenberg (2012) and Barrett and Dannenberg (2014) introduce uncertainty regarding the location of the threshold. Dannenberg et al. (2015) consider an ambiguous threshold. The results show that cooperation is hindered by uncertainty and even more by ambiguity.

The role of risk and ambiguity preferences has also been carefully studied in the economic literature. Risk aversion has long been recognized as a key determinant of individual behaviors (Pratt, 1964). Its effect on various decisions has been considered: insurance (Mossin, 1968), self-insurance

and self-protection (Ehrlich and Becker, 1972), the level of effort (i.e., preventing activity) (Jullien et al., 1999), timber harvesting (Brunette et al., 2017b), etc. In particular, De Pinto et al. (2013) show that considering risk neutral farmers whereas they are risk averse leads to miscalculate the incentives required to induce participation to a mitigation policy, like carbon sequestration programs. Truong and Trück (2016) show that assuming risk neutrality rather than risk aversion results in an unnecessary delay of investments in adaptation policies.

Regarding ambiguity preferences, Ellsberg (1961) is the first to identify this tendency to avoid ambiguous situations and to prefer risky ones. As for risk preferences, ambiguity aversion has been widely considered to characterize numerous individual decisions: value of a statistical life (Treich, 2010), portfolio choices (Gollier, 2011), insurance and self-protection (Alary et al., 2013), etc. Especially, Berger et al. (2017) show how ambiguity aversion influences the optimal level of mitigation. They proposed an integrated assessment model that generates quantitative estimates of the impact of ambiguity aversion on optimal emissions reduction. Brunette et al. (2017a) analyse the relevancy of considering adaptation efforts in an insurance contract to lower the financial cost of the insurance premium when climate change makes the probability of the natural event occurring uncertain. They show that including adaptation efforts in the insurance contract leads to an increase in the adaptation efforts of risk-averse and ambiguity-averse agents. In the same vein, Brunette et al. (2020), combining an elicitation method and survey questions, show that risk aversion has a significant and negative impact on the probability to adapt and on the intensity of adaptation, whereas ambiguity aversion has no effect. Alpizar et al. (2011) study the role of ambiguity aversion in the choice to adapt to climate change. By means of a framed field experiment with coffee farmers in Costa Rica, they find that ambiguity aversion fosters the adoption of technologies for adaptation.

Preferences toward risk and ambiguity have been found to explain various individual choices and, in particular, mitigation and adaptation decisions. Our study aims at looking at the effects of these preferences on the choice of climate policies. To the best of our knowledge, this is the first experiment that examines the trade-off between mitigation and adaptation by considering a risky context and an ambiguous one. Anticipating our results, we find that: i) there is no difference in average contributions between treatments; ii) risk and ambiguity preferences impact the decisions to mitigate or to adapt; iii) ambiguity preferences explain the intensity of the willingness to pay to obtain information.

The rest of the chapter is organized as follows. In Section 3.2, we present the experimental design. In Section 3.3, the results are described. Section 3.4 provides a discussion of the results and concludes.

3.2 Experimental design

3.2.1 Main game

The experiment consists of a repeated game played for ten periods. Subjects are divided into groups of four. The groups remain unchanged throughout all the periods of the game. At the beginning of each period, subjects receive an endowment of 250 ECUs that allows them to recover from a potential loss of 200 ECUs, and a climate budget of 25 tokens which has to be entirely spent on climate policies (i.e., mitigation and adaptation). Following Hasson et al. (2010, 2012), we do not give subjects the opportunity to ‘do nothing’, that is, to ignore climate change and keep their tokens for themselves. While the experiment would gain in external validity with that third option, it would also prevent us from analyzing the real-life trade-off between adaptation and mitigation in the fight against climate change. In each period, every group faces a risk of incurring a climatic event that can cause a loss of 200 ECUs for each member. Subjects must decide, at the same time and without communicating with each other, on the allocation of their climate budget between adaptation and mitigation measures.

A token invested in mitigation reduces the probability of the climate event occurring for all the group members. This probability is represented by an Ellsberg urn filled with black balls (event) and white balls (no event). Depending on the treatment (see below), we use either one or all of the following mitigation urns:

- **Urn A** contains a total of 150 balls. It is initially comprised of 145 black balls and 5 white balls.
- **Urn B** contains a total of 150 balls. It is initially comprised of 125 black balls and 25 white balls.
- **Urn C** contains a total of 150 balls. It is initially comprised of 105 black balls and 45 white balls.

Every token contributed to mitigation replaces a black ball with a white ball in the urn, thus it reduces the probability by 0.67%. Therefore, the probability decreases as group members allocate their tokens to mitigation and is given by the following function:

$$P = \frac{B^u - \sum_{i=1}^4 x_i}{150}$$

where x_i is the number of tokens contributed to mitigation by subject i , $i \in \{1, 4\}$, and B^u is the initial number of black balls in the mitigation urn ($u = A, B, C$).

However, a token contributed to adaptation reduces the size of the potential loss only for the individual who decides to adapt to climate change. The reduction of the loss follows this linear function:

$$L(x_i) = (1 - 0.013(25 - x_i))200$$

where $(25 - x_i)$ represents the number of tokens invested in adaptation by subject i . In order to help subjects make their decisions, a table displaying the amount of the loss for every token invested in adaptation is included in the instructions (see Appendix 3.B).

The value of the marginal per capita return from mitigation ($MPCR_m$) and the marginal per capita return from adaptation ($MPCR_a$) ensure that there exists a social dilemma since:

$$MPCR_m < MPCR_a < 4 \cdot MPCR_m \Leftrightarrow 0.0067 < 0.013 < 0.0268.$$

Therefore, it is in the interest of selfish and payoff-maximizing subjects not to invest in mitigation.

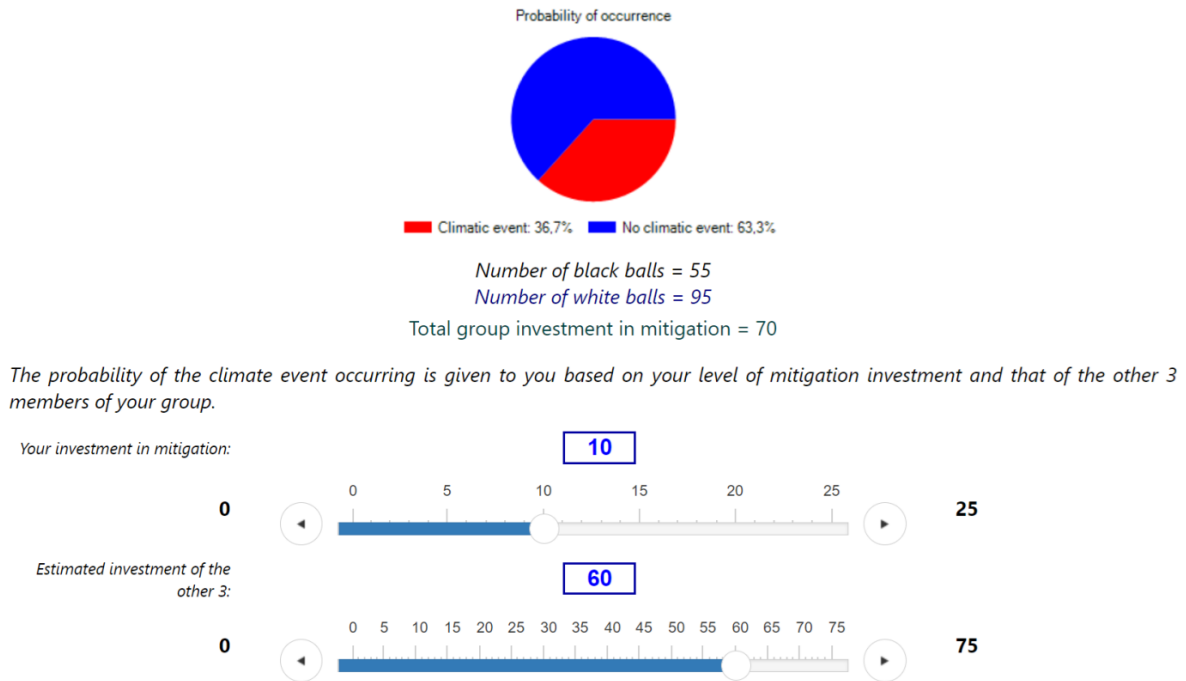
3.2.2 Treatments

In this subsection, we present the three different treatments implemented in this experiment: risk (R), ambiguity (Amb), and information acquisition (IA).

3.2.2.1 Risk (R)

In the treatment risk (R), subjects are in a risky situation. They face the mitigation urn B. They know the initial composition of the urn and are thus aware that if no token is contributed to mitigation, the probability of an event occurring for the group is 83.3%, while if the four

Figure 3.1: Resulting probability in Risk



group members invest their entire climate budget in mitigation, the probability decreases down to 16.7%.⁸ In order to facilitate the subjects' decision making, we give them access to two sliders. The first one allows them to simulate their own level of contribution to mitigation, while the second one represents the total investment of the three other group members. According to the position of the sliders, the resulting probability is displayed in a pie chart (see Figure 3.1).

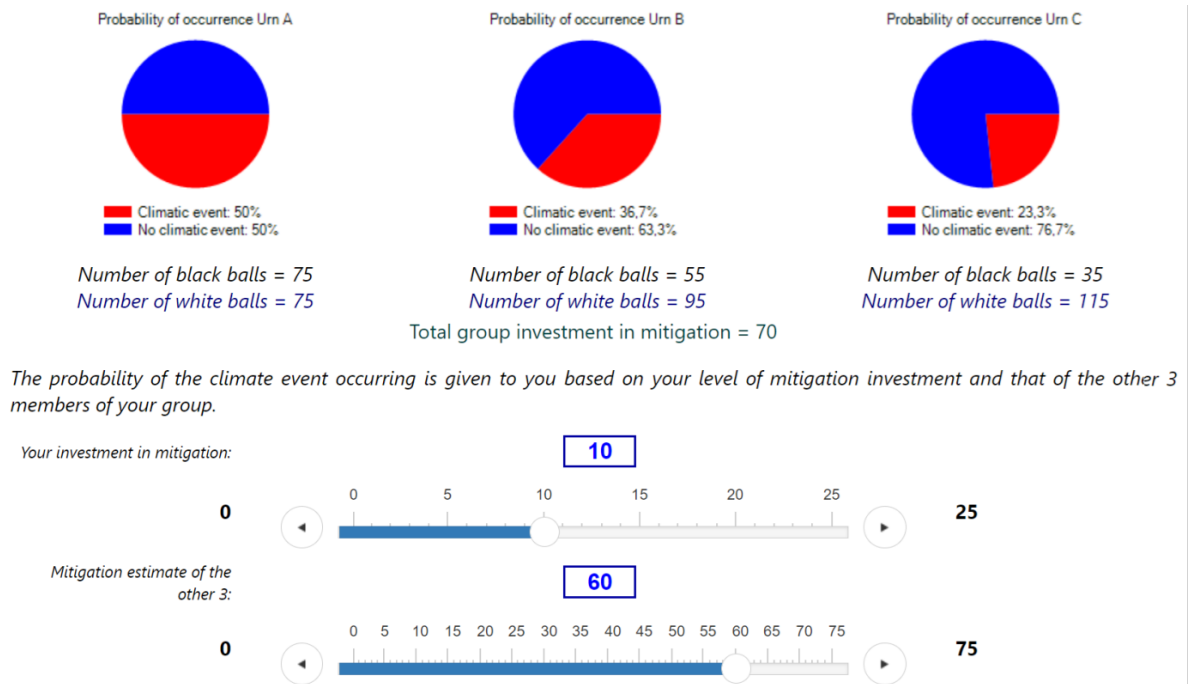
3.2.2.2 Ambiguity (Amb)

In the treatment ambiguity (Amb), subjects are in an ambiguous situation with regard to the probability of a climate event occurring. Indeed, they face the three mitigation urns (A, B, C) without knowing which one will be selected. They make their allocation decisions considering the three different possible states of nature, with urn A representing the most adverse state and urn C corresponding to the most favorable one. They are aware of the initial composition of each urn, so that they know that the probability of:

- **Urn A** goes from 96.7% if no one contributes to mitigation, to 30% if the four group members invest their 25 tokens in mitigation.

⁸There is still a climatic risk even if all members mitigate at the maximum possible level (25 tokens). This reflects the fact that, as stated by the IPCC sixth assessment report, climate hazards will multiply in the near term when global warming reaches 1.5°C.

Figure 3.2: Resulting probabilities in Ambiguity



- **Urn B** goes from 83.3% if no one contributes to mitigation, to 16.7% if the four group members invest their 25 tokens in mitigation.
- **Urn C** goes from 70% if no one contributes to mitigation, to 3.3% if the four group members invest their 25 tokens in mitigation.

In order to facilitate the subjects' decision making, they also have access to the two sliders in order to simulate their own level of contribution to mitigation and the total investment of the three other group members. According to the position of the sliders, the resulting probability for each mitigation urn is displayed in a pie chart (see Figure 3.2).

Following Attanasi et al. (2014), we use a two-stage lottery to determine the occurrence of a climate event. To that end, in each period, an opaque big urn which contains one hundred mitigation urns of three different compositions (urn A, urn B, and urn C) is generated. Subjects do not know the proportion of urns A, B and C in the big urn nor the mitigation urn which is randomly drawn from the big opaque one. Therefore, they do not precisely know the probability of a climate damage occurring in the treatment ambiguity.

3.2.2.3 Information acquisition (IA)

In the treatment information acquisition (IA), subjects are initially confronting the three mitigation urns and they have the possibility to buy information in order to know which of the three urns they will actually face. To do so, they can use up to 50 ECUs from their endowment of 250 ECUs.⁹ Subjects are asked to indicate the maximum price at which they are willing to buy information about the selected urn.¹⁰ This price should give us an approximation of the subjects' willingness to pay (WTP) to eliminate ambiguity. In every period, the computer randomly generates a number for each group which determines the actual price of information. If the price indicated by a subject is equal to or higher than the one set by the computer, the subject learns the selected mitigation urn and pays the computer's price. Otherwise, the subject does not get information and pays nothing.¹¹

In each treatment, subjects make the same decision, that is, they decide how many tokens they want to allocate to mitigation and how many they want to invest in adaptation. In Amb and IA, prior to this decision, subjects have to indicate which urn they think they will face (A, B, C, or "I do not know"). Then, in IA, subjects must reveal their willingness to pay to obtain information. If they get information, they take their allocation decision in a risky context, facing either urn A, B, or C. If they do not receive information, they make their decision in an ambiguous context (as in Amb). Regardless of the treatment condition, subjects also have to declare how many tokens they think the three other members will invest in mitigation. They are rewarded according to the precision of their beliefs.¹²

Their gains, for each period, depend on whether or not a climate event occurs. It is determined by a random draw of a ball (black or white) from the mitigation urn B in R and from the selected mitigation urn (i.e., either A, B, or C) in Amb and IA. If there is a climate event, in R and Amb, subjects get their endowment of 250 ECUs minus the amount of the loss whose size depends on their investment in adaptation. In IA, they get their endowment of 250 ECUs minus the amount of the loss, minus the price of information if they had access to it. If no climatic damage

⁹This way, they still have at least 200 ECUs to cover the risk of a climate damage.

¹⁰They have to choose an amount of ECUs included in $\{0, 5, 10, 15, \dots, 45, 50\}$. If they indicate 0, it means that they do not wish to have access to information.

¹¹This procedure can be assimilated to a Becker et al.'s (1964) (BDM) mechanism. However, instead of asking the smallest amount of cash subjects are willing to accept in exchange of their wager, they must state the highest price at which they are willing to buy information.

¹²Following Gächter and Renner (2010) and Blanco et al. (2010), we incentivize subjects' beliefs. They earn 25 additional ECUs if they correctly (± 7 tokens) predict the total investment of the three other members.

occurs, in R and Amb, subjects get their endowment of 250 ECUs, and in IA, they receive their endowment of 250 ECUs minus the price of information if they got it.

At the end of each period, subjects are informed of the drawn urn in Amb and IA, the total investment of their group in mitigation, the resulting probability, the occurrence of the climate event, and their own payoffs.

3.2.3 Subjects' preferences

After the ten periods of the main game, we use two questionnaires to assess the environmental sensitivity of subjects. The first one investigates subjects' pro-environmental behaviors. They must answer to the fifteen statements by indicating the frequency (between 1 'never' and 5 'always') with which they adopt pro-environmental attitudes (see Appendix 3.B). The second one is the New Ecological Paradigm (NEP) scale (Dunlap et al., 2000). It aims to assess the ecological consciousness of subjects. They have to indicate (using a Likert scale from 1 'strongly disagree' to 5 'strongly agree') whether or not they agree with the fifteen sentences regarding limits to growth, anti-anthropocentrism, fragility of balance, rejection of exemptionalism, and ecocrisis (see Appendix 3.B).

We also measure Social Value Orientation (SVO) of subjects following Murphy et al. (2011).¹³ To do so, subjects are randomly grouped in pairs and have to decide how they want to allocate resources between themselves and the other person. For the six different propositions, subjects must indicate which distribution of resources they prefer (see Appendix 3.B). According to their answers to the six propositions, it is possible to classify them into four categories: altruistic, prosocial, individualistic, and competitive.

Finally, we assess the subjects' preferences toward risk and ambiguity.¹⁴ We follow Chakravarty and Roy (2009) who use a multiple price list method to disentangle risk attitude and ambiguity attitude within a Klibanoff et al. (2005) (KMM) framework. Before completing these two tasks, subjects have to select their winning color (yellow or blue). In the first task, they must choose between a lottery with known probabilities (represented by an urn comprised of 5 yellow balls and 5 blue balls) and ten fixed amounts of money. More specifically, they have to make a choice between the Left option which is a lottery with two outcomes (0 € and 10 €) and 50% chance of

¹³This task is incentivized, see Subsection 3.2.4.

¹⁴One of these two tasks is incentivized, see Subsection 3.2.4.

getting either 0 € or 10 €, and the Right option which provides a safe amount of money, from 1 € in the first proposition, 2 € in the second one, to 10 € in the tenth one (see Appendix 3.B). For the ten propositions, subjects have to indicate whether they prefer the Left or the Right option.¹⁵ The switching point between the two options determines the subjects' preference toward risk. Similarly, in the second task, subjects also have to choose between the Left and the Right option. The only difference is that they do not know the composition of the urn. Therefore, they have to decide between a lottery with two outcomes (0 € and 10 €) and unknown probabilities, and a sure amount of money, from 1 € in the first proposition, 2 € in the second one, to 10 € in the tenth one (see Appendix 3.B). The switching point of subjects in the second task expresses their preference toward ambiguity.

3.2.4 Procedure

A total of 192 subjects participated in 12 sessions (4 sessions per treatment) in September, October and November 2021 in Strasbourg and in Nancy. Each subject participated in one treatment only. Half of the subjects were recruited from a list of experimental subjects maintained at the Laboratory of Experimental Economics of Strasbourg (LEES) using the ORSEE software (Greiner, 2015). We contacted the other half by mail because we targeted students who were pursuing environmental studies. Since those students are supposed to be more committed to the environmental cause, we wanted to assess whether environmental policy should be designed according to the target audience. Therefore, three sessions were run with students from the National School for Water and Environmental Engineering of Strasbourg (ENGEES) and three others with students from AgroParisTech (APT) in the campus of Nancy. Apart from the location, the conditions of the experiment were the same for each session. Table 3.1 summarizes the number of sessions and subjects per treatment for all subjects (All) and for the two subcategories of subjects: subjects whose studies are not specifically environment-related (Classic) and those who pursue environmental studies (Environment).¹⁶ The latter category corresponds to the students from ENGEES and APT.

All subjects completed the experiment using tablet computers. Each session followed an identical procedure. The instructions were read aloud by the experimenter and, before starting, subjects

¹⁵We impose monotonicity so that individuals can only have one switching point.

¹⁶Appendix 3.A provides a brief comparison of the two subcategories of subjects.

Table 3.1: Number of sessions and subjects per treatment

Treat.	Categ.	All		Classic		Environment	
		Sessions	Subjects	Sessions	Subjects	Sessions	Subjects
	R	4	64	2	32	2	32
	Amb	4	64	2	32	2	32
	IA	4	64	2	32	2	32
	Total	12	192	6	96	6	96

had to respond to a comprehension questionnaire in order to check that they properly understood the rules. The experiment could start only after all subjects had cleared the control questions. After the ten periods of the main game, subjects completed the questionnaire about their environmental attitudes and the NEP. The last parts of the experiment consisted of the SVO and the elicitation of risk and ambiguity preferences. Finally, subjects answered a post-experimental questionnaire (see Appendix 3.B).

At the end of the experiment, one period from the main game was randomly selected for actual payment. For the SVO, a random draw was made to determine which of the six propositions would actually be paid out. Either the risk elicitation task or the ambiguity elicitation task was rewarded and it also depended on a random draw. Independently of the task selected at random, the computer selected the proposition which would be compensated. If, for that proposition, a subject chose the Left option, then the computer randomly drew a ball from the urn. If the ball was the same color as the subject's winning color, the subject got 10€. Otherwise, the subject got 0€. However, if a subject chose the Right option, the subject got the amount corresponding to the proposition selected by the computer. The conversion rate was 100 ECUs to 4€ for the main game and the SVO. Subjects were paid their earnings privately at the end of the session. A session lasted 100 minutes on average and the average earnings were 20.85€ (std. dev. = 4.77). The next section presents the results.

3.3 Results

Recall that subjects have a climate budget of 25 tokens to fully allocate between mitigation and adaptation. We choose to consider, as our variable of interest, the amount of tokens contributed to the mitigation measure. However, the opposite results are true for adaptation. We proceed in two steps to analyse the results. First, we focus on average contributions to mitigation, then we

study the individual decisions to mitigate or to adapt and we run a series of regressions.

3.3.1 Average contributions

In Table 3.2, we present the average contributions to mitigation per treatment for all subjects (All) and for the two subcategories of subjects (Classic and Environment). First, we compare the treatments R and Amb in order to assess the effect of introducing ambiguity in the game. For the whole sample of subjects, in R, average contributions equal 17.28 tokens and represent 69.12% of the climate budget of 25 tokens. In Amb, contributions are lower than in R. Subject invest on average 16.49 tokens in mitigation, that is, 65.96% of their climate budget. However, this difference is not significant according to a two-sided Mann-Whitney (MW) ranksum test taking group averages as the unit of observation ($p = 0.4177$).¹⁷ The same analysis holds for Classic subjects. The average level of contributions is higher in R (17.34) than in Amb (16.28). The difference in average contributions is not significant ($p = 0.5632$). For environment subjects, we see that mean contributions are also higher in R (17.21) than in Amb (16.70). Once again, this difference is not statistically significant ($p = 0.5992$). A possible explanation of that result may be that, in Amb, subjects are, on average, neutral with regard to ambiguity. Indeed, as shown in Table 3.4, in this treatment, the average value of *Ambiguity aversion* is 5.22, meaning that subjects are slightly ambiguity averse. However, a two-tailed *t*-test indicates that this value is not significantly different from 5 which represents neutrality with respect to ambiguity ($p = 0.1675$). Therefore, subjects do not react to the introduction of ambiguity in comparison with the treatment R. In subsection 3.3.2, we control for the individual preferences toward risk and ambiguity so that it allows us to assess their effect on the contributions to mitigation.

In a second step, we compare the treatments Amb and IA in order to look at the impact of the possibility to buy information.¹⁸ Focusing first on All subjects, we see that the level of contributions is lower in IA (15.35 tokens or 61.4% of the climate budget) than in Amb (16.49 tokens or 65.96% of the climate budget). The difference is not significant ($p = 0.4070$). Classic subjects follow the same pattern, they invest less on average in IA (13.31) than in Amb (16.28). Nevertheless, the difference is not statistically significant ($p = 0.1132$). However, for Environment

¹⁷In this paragraph and the next two ones, unless specifically noted, we report the significance levels of a two-sided MW ranksum test taking group averages as the unit of observation.

¹⁸We acknowledge that the analysis of this effect, by looking at average contributions, may be thorny. Indeed, in IA, subjects can either be in a risky situation or in an ambiguous one when making their decisions. However, most of the time (78.12%), they are in an ambiguous context.

subjects, the level of contributions is slightly higher in IA (17.40) than in Amb (16.70). Here again, the difference is not statistically significant ($p = 1$). In IA, subjects are, on average, slightly risk lover (the average value of *Risk aversion* in Table 3.4 is 4.84) and slightly ambiguity averse (the average value of *Ambiguity aversion* in Table 3.4 is 5.34). However, none of these values is significantly different from 5 according to a two-tailed *t*-test (the *p*-values are respectively 0.4985 and 0.2126). This can explain that subjects do not respond to the possibility of obtaining information with respect to Amb.

Between Classic and Environment subjects, we find a difference in mean contributions in the treatment information acquisition. Classic subjects invest less on average (13.31) than Environment ones (17.40). However, this difference is only slightly significant ($p = 0.0929$). There is no significant difference for the other treatments.¹⁹ It ensues from the above the following result.

Result 1 *Introducing ambiguity with respect to the probability of a climate damage occurring does not affect average contributions to mitigation, just like the possibility of acquiring information to eliminate that ambiguity does not modify average contributions.*

Table 3.2: Mean, minimum and maximum contributions to mitigation (std. dev. in parentheses)

Treatment	Mean contrib.	% of no contrib.	% of full contrib.
All			
R	17.28 (7.18)	4.22% (20.12)	27.03% (44.45)
Amb	16.49 (7.07)	4.06% (19.76)	22.65% (41.89)
IA	15.35 (8.98)	11.09% (31.43)	29.84% (45.79)
Classic			
R	17.34 (7.38)	4.38% (20.49)	29.69% (45.76)
Amb	16.28 (7.24)	5.63% (23.08)	23.75% (42.62)
IA	13.31 (9.38)	15.63% (36.37)	24.69% (43.19)
Environment			
R	17.21 (6.99)	4.06% (19.77)	24.38% (43.00)
Amb	16.70 (6.91)	2.5% (15.64)	21.56% (41.19)
IA	17.40 (8.06)	6.56% (24.80)	35% (47.77)

In table 3.2, we also report the percentages of time subjects do not invest in mitigation (0 token contributed) and the percentages of time they contribute their entire climate budget (25 tokens) per treatment and for the different categories of subjects. If we first consider the treatments R and Amb, we find that, for the whole sample of subjects (All), the percentages of no contribution

¹⁹Classic vs. Environment in R ($p = 0.6742$), in Amb ($p = 0.7527$).

are around 4% (respectively 4.22% and 4.06%, $p = 0.6417$).²⁰ Regarding the proportions of maximum contributions, subjects invest all of their tokens more often in R (27.03%) than in Amb (22.65%) ($p = 0.6056$).²¹ For Classic subjects, the proportion of minimum contributions is slightly higher in Amb (5.63%) than in R (4.38%) ($p = 0.9764$). Concerning the percentages of full contributions, that proportion is higher in R (29.69%) than in Amb (23.75%) ($p = 0.6842$). If we now look at Environment subjects, we see that the percentage of no contribution is higher in R (4.06%) than in Amb (2.5%) ($p = 0.4492$). These subjects invest their entire climate budget in mitigation more often in R (24.38%) than in Amb (21.56%) ($p = 0.7539$).

With the aim of assessing the effect of the possibility to acquire information on the proportions of minimum and maximum contributions, we now compare the treatments Amb and IA. For All subjects, the percentage of no contribution is higher in IA (11.09%) than in Amb (4.06%) ($p = 0.2162$). The proportion of maximum contributions is significantly higher in IA (29.84%) than in Amb (22.65%) ($p = 0.0605$). For Classic subjects, the percentage of no contribution is significantly higher in IA (15.63%) than in Amb (5.63%) ($p = 0.0808$). Regarding the proportions of maximum contributions, there is no significant difference between Amb (23.75%) and IA (24.69%) ($p = 0.5110$). For Environment subjects, the opposite results hold. There is no difference in the percentages of minimum contributions between Amb (2.5%) and IA (6.56%) ($p = 0.7379$). However, the proportion of maximum contributions is significantly higher in IA (35%) than in Amb (21.56%) ($p = 0.0493$). On the basis of the above, we formulate the next result.

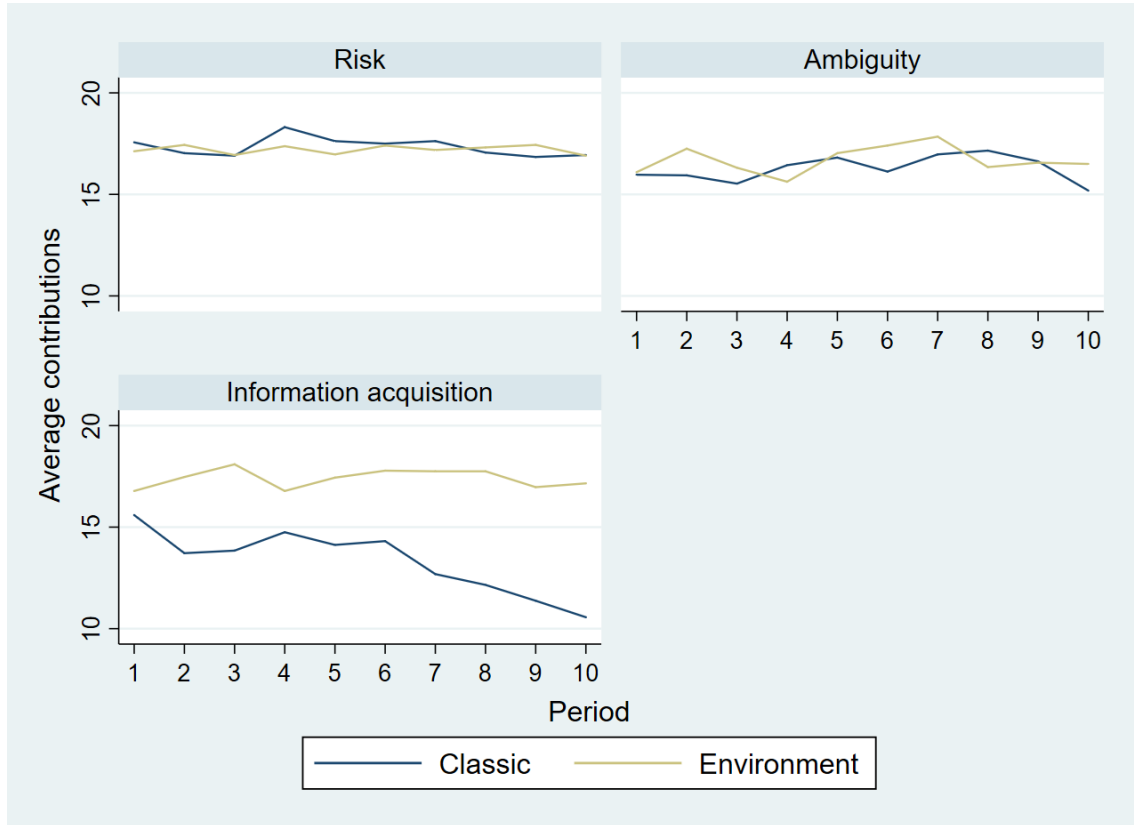
Result 2 *The possibility to buy information to completely reduce ambiguity affects Classic and Environment subjects differently. For Classic subjects, the proportion of minimum contributions is higher than in Amb, while for Environment subjects, the percentage of maximum contributions is higher than in Amb.*

Between the two subcategories of subjects, the only difference lies in the proportions of minimum contributions in IA. Classic subjects tend to contribute 0 token more often (15.63%) than Environment ones (6.56%) ($p = 0.0119$). It can explain why average contributions are lower for Classic subjects than for Environmental ones. This pattern can be observed at the bottom

²⁰In this paragraph and the next two ones, whenever we consider minimum contributions, we report the significance levels of a two-sided MW ranksum test taking the number of times 0 token is invested in mitigation by individuals as the unit of observation.

²¹In this paragraph and the next two ones, whenever we consider maximum contributions, we report the significance levels of a two-sided MW ranksum test taking the number of times 25 tokens are invested in mitigation by individuals as the unit of observation.

Figure 3.3: Average contributions to mitigation over time per treatment



of Figure 3.3 which represents the average contributions to mitigation per period for the two subcategories of subjects. We see that, in IA, average contributions of Classic subjects tend to decrease over time, especially in the last periods of the game.²²

3.3.1.1 Information acquisition treatment

In this treatment, we distinguish between subjects who wish to obtain information about the selected urn (i.e., $WTP > 0$) and those who do not (i.e., $WTP = 0$) (respectively wish yes/wish no). We also identify subjects who actually get information (i.e., $WTP \geq \text{price}$) and those who do not (i.e., $WTP < \text{price}$) (respectively info yes/info no). The first panel of table 3.3 summarizes the number of times subjects wish to receive information and the number of times they get it, as well as their willingness to pay to eliminate ambiguity. In 52.97% of the cases, subjects wish to obtain information. In particular, Classic subjects wish to get information in 56.25% of the

²²Further econometric analysis shows that Classic subjects are more likely to invest 0 token in mitigation as time goes by than Environment subjects. Results available upon request.

Table 3.3: WTP and mean contributions according to the urn (std. dev. in parentheses)

				All		Classic		Environment	
				Obs.	WTP	Obs.	WTP	Obs.	WTP
Wish	no			301	0	140	0	161	0
	yes			339	20.22 (12.53)	180	17.14 (10.87)	159	23.71 (13.39)
	yes	Info	yes	140	28.46 (14.39)	56	24.20 (14.29)	84	31.31 (13.82)
	yes		no	199	14.42 (6.40)	124	13.95 (6.90)	75	15.20 (5.42)
				Obs.	Mean contrib.	Obs.	Mean contrib.	Obs.	Mean contrib.
Info	yes	Urn	A	28	14.68 (9.94)	12	13.83 (10.83)	16	15.31 (9.53)
	yes		B	69	18.35 (6.57)	28	16.96 (8.40)	41	19.29 (4.85)
	yes		C	43	20.23 (7.10)	16	17.69 (8.62)	27	21.74 (5.68)

cases and Environment subjects wish to obtain it in 49.69% of the cases.²³ Subjects actually get information in 21.88% of the cases; 17.5% for Classic subjects and 26.25% for Environment subjects.²⁴ However, 31.09% of the time, subjects who wish to have access to information do not obtain it. There are more cases of non-acquisition of information for Classic subjects (38.75%) than for Environment subjects (23.44%).²⁵ This can be explained by the fact that, on average, Environment subjects are willing to pay more (23.71) to get information than Classic subjects (17.14).

In the second panel of Table 3.3, we look at the average number of tokens subjects contribute to mitigation when they get information about the selected urn. Subjects invest the least in mitigation (14.68) when they face urn A (unfavorable state). Classic subjects contribute 13.83 tokens on average and Environment subjects invest 15.31 tokens. Mean contributions are higher when subjects are aware that urn B is drawn (18.35). Classic subjects invest an average of 16.96 tokens and Environment subjects contribute 19.29 tokens on average. When they face urn C (favorable state), mean contributions are the highest (20.23). Classic subjects invest 17.69 tokens on average and the mean contribution of Environment subject is 21.74 tokens. It seems that subjects use the information they receive and that they condition their contributions to the mitigation urn they face. This will be further investigated in the next subsection when looking at individual decisions to mitigate or to adapt.

²³The difference between Classic and Environment subjects is not statistically significant according to a MW ranksum test taking the number of times individuals wish to obtain information as the unit of observation ($p = 0.4590$).

²⁴The difference between Classic and Environment subjects is not statistically significant according to a MW ranksum test taking the number of times individuals receive information as the unit of observation ($p = 0.4379$).

²⁵The difference between Classic and Environment subjects is statistically significant according to a MW ranksum test taking the number of times individuals who wish to obtain information do not get it ($p = 0.0814$).

3.3.2 Individual decisions

We now turn to the analysis of individual decisions in order to look at the determinants of the choice to mitigate or to adapt in the different treatments. We estimate tobit models with random effects since the dependent variable (the number of tokens invested in mitigation) is left-censored at 0 and right-censored at 25.²⁶ Table 3.4 presents the different variables that are used in the regressions along with some descriptive statistics and the results are presented in Tables 3.5 and 3.6.

Specification (1) of Table 3.5 focuses on the treatment risk. In this treatment, the subjects' preferences toward risk and ambiguity do not play a role in the decision to mitigate or to adapt, as evidenced by the coefficients of *Risk aversion* and *Ambiguity aversion* which are not statistically significant. While subjects face a risk of incurring a climate event, they do not confront ambiguity in this treatment. Therefore, it is not surprising that ambiguity preferences do not impact the level of contributions to mitigation. Among other results, we see that the coefficient of *Contributions belief* is positive and significant. In a similar experiment, Lefebvre and Van Driessche (2022) found the same result. In the context of public good games, Fischbacher and Gächter (2010) explained this finding by the fact that individuals are willing to cooperate in order to generate high beliefs and therefore to ensure high contributions. The total number of losses incurred by individuals negatively affects the mitigation level. It means that the more losses people incur, the less they invest in mitigation, and thus the more they adapt. Lefebvre and Van Driessche (2022) also found a negative effect of the number of losses. Unlike classic public goods games with repeated partner designs, there is no decline in contributions over time, as shown by the coefficient of *Period* which is not different from zero. This trend can be observed at the top left of Figure 3.3. The reason may be that while deviating from cooperation (i.e., not contributing to mitigation) allows the subject to decrease the size of their loss in case of a climate damage, it also has bad implication for all the group members since this subject renounces the possibility to reduce the probability of that damage occurring. Contrary to public good games where subjects have an incentive to deviate in order to increase their earnings, in this case, if they deviate, they reduce the size of their loss at the expense of not reducing the probability for the group. This can explain that subjects maintain their levels of contributions over time. There is no difference

²⁶All results are robust to the use of other specifications such as OLS or individual clustered standard errors and whether or not other socio-demographic variables are included.

Table 3.4: Variables definition and descriptive statistics per treatment

Variable	Definition	Mean (std. dev.)		
		R	Amb	IA
Risk aversion	From 0 for a person who is really risk seeking, to 9 for a person who is really risk averse	4.53 (1.69)	4.78 (1.63)	4.84 (1.82)
Ambiguity aversion	From 0 for a person who is really ambiguity seeking, to 9 for a person who is really ambiguity averse	5.00 (1.99)	5.22 (1.24)	5.34 (2.17)
Contributions belief	Subject's belief about the total contribution to mitigation of the 3 other group members	52.95 (14.32)	49.14 (14.79)	47.58 (16.44)
Partners _{p-1}	Contributions to mitigation of the 3 other group members in the previous period	51.94 (15.66)	49.67 (14.55)	46.56 (17.16)
Nb. of min. contrib.	Number of times subject invests 0 token in mitigation	0.42 (1.53)	0.41 (1.25)	1.11 (2.75)
Nb. of max. contrib.	Number of times subject invests 25 tokens in mitigation	2.70 (4.07)	2.27 (3.70)	2.98 (3.58)
Nb. of losses	Number of losses incurred over the 10 periods	3.38 (1.62)	4.25 (1.72)	4.25 (1.95)
Loss _{p-1}	1 if a loss occurred in the previous period; 0 otherwise	0.33 (0.47)	0.42 (0.49)	0.41 (0.49)
Period	1 in period 1, 2 in period 2, ..., 10 in period 10	5.50 (2.87)	5.50 (2.87)	5.50 (2.87)
Environment subjects	1 for subjects whose studies are environment-related; 0 otherwise	0.50 (0.50)	0.50 (0.50)	0.50 (0.50)
Urn A belief	1 if subject believes that urn A will be drawn; 0 otherwise		0.21 (0.41)	0.23 (0.42)
Urn B belief	1 if subject believes that urn B will be drawn; 0 otherwise		0.23 (0.42)	0.25 (0.44)
Urn C belief	1 if subject believes that urn C will be drawn; 0 otherwise		0.27 (0.44)	0.27 (0.44)
No urn belief	1 if subjects does not know which urn will be drawn; 0 otherwise		0.29 (0.45)	0.25 (0.43)
Urn A _{p-1}	1 if urn A was drawn in the previous period; 0 otherwise		0.27 (0.44)	0.26 (0.44)
Urn B _{p-1}	1 if urn B was drawn in the previous period; 0 otherwise		0.37 (0.48)	0.42 (0.49)
Urn C _{p-1}	1 if urn C was drawn in the previous period; 0 otherwise		0.36 (0.48)	0.32 (0.47)
Info*urn A	1 if subject obtains information and the drawn urn is A; 0 otherwise			0.04 (0.20)
Info*urn B	1 if subject obtains information and the drawn urn is B; 0 otherwise			0.11 (0.31)
Info*urn C	1 if subject obtains information and the drawn urn is C; 0 otherwise			0.07 (0.25)
Age	Age of subject	22.16 (2.65)	21.83 (2.34)	21.48 (2.81)
Female	1 if subject is female; 0 otherwise	0.52 (0.50)	0.64 (0.54)	0.56 (0.53)

in behavior between Classic subjects and Environment ones since the coefficient of *Environment subjects* is not significant. This confirms the non parametric result obtained in the previous subsection.

In specification (2) of Table 3.5, we look at the treatment ambiguity. What is interesting is that preferences toward ambiguity affect the contributions to mitigation. Indeed, the coefficient of *Ambiguity aversion* is negative and significant. It means that the more subjects' preferences tend toward ambiguity aversion, the less subjects mitigate. Recall that both measures allow for

a diminution in the expected loss, through a decrease in probability if subjects mitigate, and through a decrease in the magnitude of the loss if subjects adapt to climate change. However, in this treatment, subjects do not know which urn they will face so that the probability of a climate damage occurring is ambiguous. Therefore, it makes sense that subjects who are ambiguity averse invest less in the ambiguous option (i.e., mitigation) for the benefit of the non-ambiguous one (i.e., adaptation). Thus, we present the next result.

Result 3 *Ambiguity preferences affect the contributions to mitigation in an ambiguous context. The more subjects' preferences tend toward ambiguity aversion, the less subjects invest in mitigation.*

Still from specification (2) of Table 3.5, we notice that the beliefs about the other members' contributions and the number of losses have the same effect as in specification (1). However, since there is ambiguity in this treatment, subjects also rely on the occurrence of a loss in the previous period. It negatively impacts the level of contributions to mitigation. In an experiment comparable to ours, apart from the fact that subjects have a third possibility to invest their ECUs (i.e., they can increase their own payoffs), Blanco et al. (2020) found a similar result. It means that after experiencing a climatic event, people will turn away from mitigation in order to adapt more to global warming. As shown by the coefficient of *Period* which is not significant, in this treatment, just as in R, contributions to mitigation do not decrease through periods. This is illustrated at the top right of Figure 3.3. The coefficient of *Environment subjects* is not different from zero which means that Environment subjects do not behave differently than Classic ones and which is in line with the non parametric result. The subjects' beliefs about the drawn urn play a role in the decision to mitigate or to adapt. Indeed, we see that subjects who believe that Urn A²⁷ will be drawn (unfavorable state) invest less than if they believe Urn B will be drawn, or if they believe Urn C will be drawn (favorable state), or if they do not know which urn will be drawn. Thus, if they think they will be in the most adverse state (greater chances of damages), subjects mitigate less than in any other situations, and thus adapt more. We also see that the level of mitigation does not depend on the urn subjects faced in the previous period.

Finally, in specification (3) of Table 3.5, we focus on the treatment information acquisition. Regarding risk and ambiguity preferences, we notice that, unlike in Amb, the subjects' preferences

²⁷The dummy *Urn A belief* is not included in regression (2) nor (3) since it is the baseline.

Table 3.5: Tobit estimations per treatment

Dependent variable: Contributions to mitigation	Risk (R) (1)	Ambiguity (Amb) (2)	Information acquisition (IA) (3)
Risk aversion	0.111 (0.669)	-.418 (0.532)	-1.779* (0.892)
Ambiguity aversion	-.516 (0.568)	-1.901** (0.682)	0.45 (0.76)
Contributions belief	0.179*** (0.029)	0.265*** (0.029)	0.365*** (0.036)
Nb. of losses	-2.409*** (0.699)	-1.219* (0.5)	-.841 (0.823)
Loss _{p-1}	-.236 (0.416)	-1.331** (0.455)	-.276 (0.843)
Period	-.055 (0.072)	-.059 (0.083)	-.413** (0.129)
Environment subjects	-1.551 (2.177)	-1.357 (1.744)	3.190 (3.218)
Urn B belief		1.889** (0.668)	0.044 (1.106)
Urn C belief		2.083** (0.639)	1.394 (1.044)
No urn belief		3.524*** (1.022)	1.049 (1.656)
Urn B _{p-1}		-.078 (0.559)	0.404 (0.888)
Urn C _{p-1}		-.565 (0.547)	0.188 (1.020)
Wish			-1.377 (1.283)
Info*Urn A			-.929 (1.609)
Info*Urn B			4.194*** (1.231)
Info*Urn C			3.325* (1.426)
Age	-.343 (0.392)	-.345 (0.396)	-.453 (0.571)
Female	-1.607 (2.154)	-3.232 (1.772)	-2.197 (3.054)
Constant	29.639** (11.218)	31.579** (10.669)	20.696 (14.710)
Obs.	576	576	576
Left-censored obs.	25	24	66
Right-censored obs.	155	132	171

Standard errors are in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

toward risk affect the level of mitigation while preferences toward ambiguity do not. It means that the more subjects' preferences tend toward risk aversion, the less subjects mitigate. In this treatment, there is the possibility to completely reduce ambiguity by buying information, thus ambiguity preferences should impact the willingness to pay to get information (see Table 3.6 below). Based on the above, we propose the following result.

Result 4 *Risk preferences are a determinant in the choice to mitigate or to adapt when there is the possibility to eliminate ambiguity. The more subjects' preferences tend toward risk aversion, the less subjects contribute to mitigation.*

Still from specification (3) of Table 3.5, we see that, as in Amb, the subjects' beliefs about the total contribution of the other group members positively affect the level of mitigation. However, the number of losses and the occurrence of a loss in the previous period do not affect the level of contributions in this treatment. Unlike in Amb, there is a negative effect of time, as expressed by the negative and significant coefficient of *Period*. Contributions to mitigation tend to decline over time. There is no econometric evidence of a difference between Environment and Classic subjects since the coefficient of *Environment subjects* is not statistically significant. The possibility to obtain information wipes out the effects of the beliefs about the selected mitigation urns. Indeed, none of these dummy coefficients is significant. We also see that subjects who wish to get information do not behave differently than those who do not, as evidenced by the coefficient of *Wish* which is not significant. What is of particular interest is that subjects who receive information actually use it. Indeed, if subjects know that the drawn urn is B or C, they mitigate more than subjects who do not know which urn they face. However, there is no difference in contributions between subjects who know that they face urn A (unfavorable state) and those who do not have information, since the coefficient of *Info*Urn A* is not significant. The fact that subjects use information is not systematic. Indeed, Gangadharan and Nemes (2009) found that, in a public good game where either the return from the public good or the private good is unknown, even when subjects learn that return, they do not take it into account in their decision making. The authors explained this finding by the subjects' aversion to strategic uncertainty. This leads us to the next result.

Result 5 *Subjects use information when they get it. They mitigate more if the chances of incurring a climate event are already low (urn B or C).*

Table 3.6: Probit and linear regressions on the WTP in IA

	Probability (1)	Intensity (2)
Risk aversion	0.010 (0.028)	0.673 (1.040)
Ambiguity aversion	0.015 (0.020)	1.480* (0.751)
Partners _{p-1}	-.001 (0.001)	-.064 (0.038)
Nb. of min. contrib.	-.114** (0.028)	-.253 (2.485)
Nb. of max. contrib.	-.033* (0.013)	-1.007* (0.509)
Nb. of losses	0.035 (0.032)	-1.441 (0.751)
Loss _{p-1}	0.029 (0.032)	0.147 (1.009)
Period	-.007 (0.006)	0.264 (0.219)
Environment subjects	-.038 (0.128)	5.411 (4.134)
Urn B belief	0.016 (0.038)	-.310 (0.9)
Urn C belief	-.039 (0.036)	-.672 (1.059)
No urn belief	-.038 (0.057)	-1.588 (1.893)
Urn B _{p-1}	0.007 (0.032)	0.477 (0.839)
Urn C _{p-1}	0.034 (0.041)	0.684 (1.037)
Age	0.004 (0.015)	0.02 (0.77)
Female	-.115 (0.100)	-2.451 (4.321)
Constant		13.543 (18.745)
Obs.	576	414

Standard errors are in parentheses and clustered by individuals.

Average marginal effects are reported in (1).

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Following Brunette et al. (2020), we proceed in two steps to analyze the subjects' willingness to pay to obtain information about the drawn urn in the treatment information acquisition. Firstly, we focus on the probability to buy information²⁸ using a probit model with random effects. Secondly, we explore the intensity with which subjects buy information²⁹ using a linear model with random effects. In specification (1) of Table 3.6, we see that subjects who contribute 0 token to mitigation more often are less likely to buy information, just like it is less likely that those who invest their entire climate budget a larger number of times buy information. The rationale may be that subjects who often contribute either the minimum or the maximum make their decisions irrespective of the drawn urn. They do not consider the state of nature in which they may be. Therefore, they do not need to buy information. If we now focus on specification (2) of Table 3.6, that is, on the intensity of the WTP, we see that ambiguity preferences matter, as evidenced by the coefficient of *Ambiguity aversion* which is positive and significant. More precisely, the more subjects' preferences tend toward ambiguity aversion, the more subjects pay to obtain information. Indeed, since the acquisition of information allows for a complete reduction of ambiguity, it makes sense that subjects who dislike ambiguity are willing to pay more in order to know the urn they will face. Snow (2010) theoretically proved, using the KMM model, that the WTP for information that resolves ambiguity increases with higher ambiguity aversion. Thus in IA, ambiguity preferences explain the intensity of the WTP to reduce ambiguity and risk preferences explicate the level of contributions to mitigation. Based on the foregoing, we express the following result.

Result 6 *Ambiguity preferences affect the intensity of the willingness to pay to reduce ambiguity. The more subjects' preferences tend to ambiguity aversion, the more subjects are willing to pay to obtain information.*

Also, subjects who contribute their entire climate budget quite often are willing to pay less to obtain information. Those subjects value less information because they may not ponder the different mitigation urns if they are used to investing their entire endowment.

²⁸The dependent variable takes the value 1 if the subjects' WTP is strictly higher than 0, and 0 otherwise.

²⁹We only consider the 48 subjects who wish to obtain information at least once.

3.4 Discussion and conclusion

This chapter investigates the role of risk and ambiguity preferences on the decision to mitigate or to adapt to climate change in a risky context, in an ambiguous one, and when there is the possibility to completely reduce ambiguity by buying information. We propose an original experiment in which each group of four subjects faces a risk of incurring a climatic damage that can cause a loss for each group member. In each treatment (i.e., risk, ambiguity, and information acquisition), subjects must decide on the allocation of their tokens between mitigation and adaptation. We find that the introduction of ambiguity as well as the possibility to buy information have no effect on average contributions to mitigation. This result can be explained by the fact that, on average, subjects are neutral to risk and ambiguity. However, when looking at individual decisions to mitigate or to adapt, we highlight the role of risk and ambiguity preferences in this choice. Indeed, in an ambiguous context, subjects who dislike ambiguity neglect mitigation policies in favor of adaptation ones. When there exists the possibility to reduce ambiguity by buying information, risk averse subjects tend to mitigate less, and thus to adapt more. This finding has policy implications since it proves that these preferences matter when it comes to the individuals' climate policies decision-making process. They should therefore be taken into account when designing climate policies. However, it has poorly been the case so far since most models gloss over the uncertainties that naturally arise from climate change (Etner et al., 2020). Furthermore, subjects are willing to pay to obtain information in order to eliminate ambiguity. More than half of the time, subjects wish to have access to information and they actually use it when they obtain it. This emphasizes the importance to make information available to individuals, whether it is through the education system, awareness campaigns, or science popularization. Alpizar et al. (2011) state that, in some situations, it could be beneficial for governments to alleviate ambiguity among individuals by providing information. It is also in line with the conclusion of Gautier et al. (2019) which states that raising awareness about the environmental challenges to come can strengthen the adoption of pro-social and pro-environmental behaviors. Finally, the fact that there is no significant difference between subjects who pursue environmental studies and those who do not proves that climate change is a global issue that affects all this generation regardless of its study interests.

Bibliography of Chapter 3

- Alary, D., Gollier, C., and Treich, N. (2013). The effect of ambiguity aversion on insurance and self-protection. *The Economic Journal*, 123:1188–1202.
- Alpizar, F., Carlsson, F., and Naranjo, M. A. (2011). The effect of ambiguous risk, and coordination on farmers' adaptation to climate change — A framed field experiment. *Ecological Economics*, 70(12):2317–2326.
- Attanasi, G., Gollier, C., Montesano, A., and Pace, N. (2014). Eliciting ambiguity aversion in unknown and in compound lotteries: a smooth ambiguity model experimental study. *Theory and Decision*, 77(4):485–530.
- Barrett, S. and Dannenberg, A. (2012). Climate negotiations under scientific uncertainty. *Proceedings of the National Academy of Sciences*, 109(43):17372–17376.
- Barrett, S. and Dannenberg, A. (2014). Sensitivity of collective action to uncertainty about climate tipping points. *Nature Climate Change*, 4(1):36–39.
- Becker, G., DeGroot, M., and Marschak, J. (1964). Measuring utility by a single-response sequential method. *Behavioral Science*, 9:226–232.
- Berger, L., Emmerling, J., and Tavoni, M. (2017). Managing Catastrophic Climate Risks Under Model Uncertainty Aversion. *Management Science*, 63(3):749–765.
- Björk, L., Kocher, M., Martinsson, P., and Nam Khanh, P. (2016). Cooperation under risk and ambiguity. Technical Report 683, University of Gothenburg, Department of Economics.
- Blanco, E., Dutcher, E. G., and Haller, T. (2020). Social dilemmas with public and private insurance against losses. *Journal of Economic Behavior & Organization*, 180:924–937.
- Blanco, M., Engelmann, D., Koch, A. K., and Normann, H.-T. (2010). Belief elicitation in experiments: is there a hedging problem? *Experimental Economics*, 13(4):412–438.
- Boucher, V. and Bramoullé, Y. (2010). Providing global public goods under uncertainty. *Journal of Public Economics*, 94(9):591–603.

- Boulou-Reshef, B., Brott, S. H., and Zylbersztein, A. (2017). Does Uncertainty Deter Provision of Public Goods? *Revue économique*, 68(5):785.
- Bramoullé, Y. and Treich, N. (2009). Can Uncertainty Alleviate the Commons Problem? *Journal of the European Economic Association*, 7(5):1042–1067.
- Brunette, M., Coutre, S., and Pannequin, F. (2017a). Is forest insurance a relevant vector to induce adaptation efforts to climate change? *Annals of Forest Science*, 74:41–49.
- Brunette, M., Foncel, J., and Kéré, E. (2017b). Attitude towards risk and production decision : An empirical analysis on french private forest owners. *Environmental Modeling and Assessment*, 22:563–576.
- Brunette, M., Hanewinkel, M., and Yousefpour, R. (2020). Risk aversion hinders forestry professionals to adapt to climate change. *Climatic Change*, 162:2157–2180.
- Camerer, C. and Weber, M. (1992). Recent developments in modeling preferences: Uncertainty and ambiguity. *Journal of Risk and Uncertainty*, 5(4):325–370.
- Chakravarty, S. and Roy, J. (2009). Recursive expected utility and the separation of attitudes towards risk and ambiguity: an experimental study. *Theory and Decision*, 66(3):199–228.
- Dannenberg, A., Löschel, A., Paolacci, G., Reif, C., and Tavoni, A. (2015). On the Provision of Public Goods with Probabilistic and Ambiguous Thresholds. *Environmental and Resource Economics*, 61(3):365–383.
- De Pinto, A., Robertson, R. D., and Darko Obiri, B. (2013). Adoption of climate change mitigation practices by risk-averse farmers in the ashanti region, ghana. *Ecological Economics*, 86:47–54.
- Dickinson, D. L. (1998). The voluntary contributions mechanism with uncertain group payoffs. *Journal of Economic Behavior & Organization*, 35(4):517–533.
- Dunlap, R., Liere, K., Mertig, A., and Jones, R. (2000). Measuring Endorsement of the New Ecological Paradigm: A Revised NEP Scale. *Journal of Social Issues*, 56:425–442.
- Ehrlich, I. and Becker, G. S. (1972). Market insurance, self-insurance, and self-protection. *The Journal of Political Economy*, 80:623–648.

- Ellsberg, D. (1961). Risk, ambiguity, and the savage axioms. *Quarterly Journal of Economics*, 75:643–669.
- Etner, J., Jeleva, M., and Raffin, N. (2020). Climate policy: How to deal with ambiguity? *Economic Theory*, 72(1):263–301.
- Fischbacher, U. and Gächter, S. (2010). Social Preferences, Beliefs, and the Dynamics of Free Riding in Public Goods Experiments. *American Economic Review*, 100(1):541–556.
- Fischbacher, U., Schudy, S., and Teyssier, S. (2014). Heterogeneous reactions to heterogeneity in returns from public goods. *Social Choice and Welfare*, 43(1):195–217.
- Fisher, J., Isaac, R. M., Schatzberg, J. W., and Walker, J. M. (1995). Heterogeneous demand for public goods: Behavior in the voluntary contributions mechanism. *Public Choice*, 85(3):249–266.
- Gangadharan, L. and Nemes, V. (2009). Experimental analysis of risk and uncertainty in provisioning private and public goods. *Economic Inquiry*, 47(1):146–164.
- Gautier, A., Hoet, B., Jacqmin, J., and Van Driessche, S. (2019). Self-consumption choice of residential PV owners under net-metering. *Energy Policy*, 128:648–653.
- Gollier, C. (2011). Portfolio choices and asset prices: the comparative statics of ambiguity aversion. *Review of Economic Studies*, 78:1329–1344.
- Greenhill, B., Dolšák, N., and Prakash, A. (2018). Exploring the Adaptation-mitigation Relationship: Does Information on the Costs of Adapting to Climate Change Influence Support for Mitigation? *Environmental Communication*, 12(7):911–927.
- Greiner, B. (2015). Subject pool recruitment procedures: organizing experiments with ORSEE. *Journal of the Economic Science Association*, 1(1):114–125.
- Gächter, S. and Renner, E. (2010). The effects of (incentivized) belief elicitation in public goods experiments. *Experimental Economics*, 13(3):364–377.
- Hasson, R., Löfgren, A., and Visser, M. (2010). Climate change in a public goods game: Investment decision in mitigation versus adaptation. *Ecological Economics*, 70:331–338.

- Hasson, R., Löfgren, A., and Visser, M. (2012). Treatment Effects of Climate Change Risk on Mitigation and Adaptation Behaviour in an Experimental Setting. *South African Journal of Economics*, 80(3):415–430.
- Ingham, A., Ma, J., and Ulph, A. (2007). Climate change, mitigation and adaptation with uncertainty and learning. *Energy Policy*, 35(11):5354–5369.
- Ingham, A., Ma, J., and Ulph, A. M. (2013). Can adaptation and mitigation be complements? *Climatic Change*, 120(1-2):39–53.
- Jullien, B., Salanié, B., and Salanié, F. (1999). Should more risk-averse agents exert more effort? *The Geneva Papers on Risk and Insurance Theory*, 24:19–28.
- Kane, S. and Shogren, J. F. (2000). Linking Adaptation and Mitigation in Climate Change Policy. *Climatic Change*, 45(1):75–102.
- Keser, C. and Montmarquette, C. (2008). Voluntary contributions to reduce expected public losses. *Journal of Economic Behavior & Organization*, 66(3-4):477–491.
- Klibanoff, P., Marinacci, M., and Mukerji, S. (2005). A Smooth Model of Decision Making under Ambiguity. *Econometrica*, 73(6):1849–1892.
- Knight, F. H. (1921). *Risk Uncertainty and Profit*. Boston: Houghton Mifflin.
- Kuusela, O.-P. and Laiho, T. (2020). The role of research in common pool problems. *Journal of Environmental Economics and Management*, 100:102287.
- Lefebvre, M. and Van Driessche, S. (2022). Climate policies under income inequality. Mimeo.
- Levati, M. V. and Morone, A. (2013). Voluntary contributions with risky and uncertain marginal returns: The importance of the parameter values. *Journal of Public Economic Theory*, 15(5):736–744.
- Levati, M. V., Morone, A., and Fiore, A. (2009). Voluntary Contributions with Imperfect Information: An Experimental Study. *Public Choice*, 138(1/2):199–216.
- McEvoy, D. M., Haller, T., and Blanco, E. (2022). The Role of Non-Binding Pledges in Social Dilemmas with Mitigation and Adaptation. *Environmental and Resource Economics*, 81(4):685–710.

- Morath, F. (2010). Strategic information acquisition and the mitigation of global warming. *Journal of Environmental Economics and Management*, 59(2):206–217.
- Mossin, J. (1968). Aspects of rational insurance purchasing. *Journal of Political Economy*, pages 553–568.
- Murphy, R. O., Ackermann, K. A., and Handgraaf, M. (2011). Measuring Social Value Orientation. *Judgment and Decision Making*, 6(8):771–781.
- Parry, M., editor (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.
- Pratt, J. W. (1964). Risk Aversion in the Small and in the Large. *Econometrica*, 32(1/2):122–136.
- Raihani, N. and Aitken, D. (2011). Uncertainty, rationality and cooperation in the context of climate change. *Climatic Change*, 108(1-2):47–55.
- Scheraga, J. D. and Grambsch, A. E. (1998). Risks, opportunities, and adaptation to climate change. *Climate Research*, 11(1):85–95.
- Snow, A. (2010). Ambiguity and the value of information. *Journal of Risk and Uncertainty*, 40(2):133–145.
- Théroutte, V. and Zylbersztein, A. (2020). Cooperation in a risky world. *Journal of Public Economic Theory*, 22(2):388–407.
- Tol, R. S. (2005). Adaptation and mitigation: trade-offs in substance and methods. *Environmental Science & Policy*, 8(6):572–578.
- Treich, N. (2010). The value of a statistical life under ambiguity aversion. *Journal of Environmental Economics and Management*, 59:15–26.
- Truong, C. and Trück, S. (2016). It’s not now or never: Implications of investment timing and risk aversion on climate adaptation to extreme events. *European Journal of Operational Research*, 253:856–868.

Appendix 3.A Comparison of Classic and Environment subjects

Based on the two environmental questionnaires, the SVO, and the two tasks related to preferences toward risk and ambiguity, we compare Classic and Environment subjects. We average the fifteen answers to the questionnaire on pro-environmental behaviors and the fifteen answers to the NEP in order to obtain two values for assessing the environmental sensitivity of subjects. We see from Table 3.A that the average pro-environmental behaviors score of Classic subjects equals 3.02 while the one of Environment subjects is 3.11. It means that, on average, Environment subjects adopt pro-environmental behaviors more often than Classic ones. The difference is significant according to a two-sided MW ranksum test ($p = 0.0301$). Regarding the NEP, Classic subjects have a lower average score (3.21) than Environment ones (3.29). This difference is significant according to a two-sided MW ranksum test ($p = 0.0712$). Relative to the SVO, there are only two different social orientations among Classic subjects: prosocial (48 subjects) and individualistic (48 subjects). For Environment subjects, we find the four different SVO types: altruist (1 subject), prosocial (67 subjects), individualist (26 subjects), and competitive (2 subjects). The Pearson χ^2 test for the independence of the rows and columns indicates that the observed differences are significant ($p = 0.0050$). Finally, regarding risk and ambiguity preferences of subjects, we see that both categories are, on average, risk lovers (4.71 for Classic subjects, 4.73 for Environment ones), and ambiguity averse (5.19 for Classic and Environment subjects). There is no difference in risk preferences ($p = 0.9764$), nor in ambiguity preferences ($p = 0.9840$) according to two-sided MW ranksum tests.

Table 3.A: Comparison of Classic and Environment subjects

Variable \ Category	Classic			Environment		
	Mean (std. dev.)	Min.	Max.	Mean (std. dev.)	Min.	Max.
Env. behaviors	3.02 (0.31)	2.27	3.6	3.11 (0.27)	2.33	3.6
NEP	3.21 (0.30)	2.33	3.8	3.29 (0.32)	2.33	4.07
Altruist	0	0	0	0.01 (0.10)	0	1
Prosocial	0.50 (0.50)	0	1	0.70 (0.46)	0	1
Individualist	0.50 (0.50)	0	1	0.27 (0.45)	0	1
Competitive	0	0	0	0.02 (0.14)	0	1
Risk aversion	4.71 (1.63)	0	9	4.73 (1.82)	0	9
Ambiguity aversion	5.19 (1.94)	0	9	5.19 (1.77)	0	9

Appendix 3.B Instructions

Translated from French to English.

In olive, the elements that change in the instructions for R only.

In red, the elements that change in the instructions for both Amb and IA.

In blue, the elements that change in the instructions for IA only.

Thank you for participating in this experiment on the economics of decision making in the context of climate change. In this experiment you will have the opportunity to make money. The amount of your payoff will depend on **your decisions and the decisions of other participants**. Therefore, we ask you to read these instructions carefully since they will help you understand the experiment. All your decisions are **anonymous**. You will never enter your name on the tablet computer. You will give your choices to the tablet computer you have received.

From now on, communication is no longer permitted. Please switch off your mobile phone as well. If you have a question, raise your hand and an experimenter will come and answer you in private.

This experiment comprises 3 parts. You have received the instructions for part 1. Each time you finish a part, you will get the instructions for the next one. All participants have the same instructions.

The earnings you can collect by taking part in this experiment are expressed in ECUs (Experimental Currency Units). At the end of each part, your earnings, in ECUs, will be converted in euros according to the conversion rate that applies to the part in question. At the end of the experiment, the gains you will have earned, converted into euros, will be paid to you in cash privately.

PART 1

For this part, the conversion rate is **100 ECUs = 4€**.

This first part of the experiment comprises 10 periods. During this part, you and 3 other randomly chosen anonymous participants will form a group of 4 persons. This group will remain the same during these 10 periods.

In this part of the experiment, your group represents a small community which must make decisions relating to climate change. In such a context, it is possible that climate events occur in the community (such as rising water leading to floods, extreme heat waves, storms, etc.). If a

climatic event occurs it entails a loss of wealth of equal size for each group member.

There exist two types of measures that can be taken by every group member in order to face climate change: mitigation measures and adaptation measures.

- The mitigation measures aim at reducing greenhouse gas emissions in the atmosphere such as, for example, sorting and reducing your waste, or even using public transport rather than your car to move around. These measures serve to decrease the probability of occurrence of climate disasters.
- The adaptation measures seek to reduce the vulnerability of a person to climate change. It consists, for example, of replacing your windows by laminated glass in order to face high winds. These measures serve to decrease the magnitude of climatic events.

Your tasks

At the beginning of each period, you will receive a wealth in ECUs and a climate budget in tokens. The climate budget must be entirely spent and you must decide on its allocation between the measures of mitigation and adaptation.

- You receive, in each period, a wealth of 250 ECUs and climate budget of 25 tokens.

In each period, you must choose how many tokens of your climate budget you want to invest in mitigation (integer) and how many tokens you want to invest in adaptation in order to face a potential climate event that would result in a loss of 200 ECUs for each group member.

Task 1 \Rightarrow You will indicate how many tokens of your climate budget you want to invest in *mitigation*. The rest of your budget will be invested in *adaptation*.

Mitigation measures

By reducing greenhouse gas emissions, investments in mitigation decrease the probability of a climate event occurring.

Since investments in mitigation reduce the emissions of greenhouse gas in the atmosphere, the whole community benefits from these investments. In other words, all the group members benefit from the reduction of probability of occurrence of a climate event whether they invested in mitigation or not.

The probability of occurrence of a climate event decreases **with your investment in mitigation and the investment of the 3 other members of your group in mitigation.**

Nevertheless, when deciding, you will not know the choice of the three other group members and the 4 of you will make your decision simultaneously.

The probability of a climate event occurring is represented by an urn filled with black and white balls. If a black ball is drawn from the urn, it means that a climatic event occurs for the current period. However, if the drawn ball is white, it means that there is no climatic event for the current period. The urn is initially comprised of 125 black balls and 25 white balls (there are thus 150 balls in total in the urn). *Each token invested in mitigation replaces a black ball with a white ball in the urn.*

The probability of a climate event occurring is represented by a small urn filled with black and white balls. If a black ball is drawn from the small urn, it means that a climatic event occurs for the current period. However, if the ball drawn from the small urn is white, it means that there is no climatic event for the current period. There are **3 different small urns** from which the draw of a ball can be done:

- Urn A which is initially comprised of 145 black balls and 5 white balls (there are thus 150 balls in total).
- Urn B which is initially comprised of 125 black balls and 25 white balls (there are thus 150 balls in total).
- Urn C which is initially comprised of 105 black balls and 45 white balls (there are thus 150 balls in total).

Each token invested in mitigation replaces a black ball with a white ball in the urn.

In each period, a mix of 100 small urns A, B, and C will be placed in a big opaque urn and the computer will randomly draw a small urn from the big opaque one in order to determine the probability of occurrence of a climate event according to the mitigation decisions of your group. When making your decision, you will not know the number of small urns A, B, and C in the big opaque one, nor the small urn which will have been randomly selected by the computer.

Let us take one example **at random** in order to explain how the probability varies:

Suppose that the 3 other group members invested in total 44 tokens in mitigation. If you decide to invest 17 tokens in mitigation, the total investment in mitigation for your group will thus be 61 tokens. It means that 61 black balls will be replaced with white balls in the urn. **The**

final composition of the urn will thus be of 64 black balls ($125-61=64$) and of 86 white balls ($25+61=86$). The probability of occurrence of the climate event will then be of 42.7% ($\frac{64}{150}$).

Thus, there will be a 42.7% chance that the climate event occurs in your group.

If no one invests in mitigation, the probability of a climate event occurring is equal to 83.3%; on the contrary, if the 4 group members invest all of their tokens in mitigation, the probability decreases down to 16.7%.

- If the computer randomly draws Urn A, the final composition of the urn will thus be of 84 black balls ($145-61=84$) and of 66 white balls ($5+61=66$). The probability of occurrence of the climate event will then be of 56% ($\frac{84}{150}$). Thus, there will be a 56% chance that the climate event occurs in your group.
- If the computer randomly draws Urn B, the final composition of the urn will thus be of 64 black balls ($125-61=64$) and of 86 white balls ($25+61=86$). The probability of occurrence of the climate event will then be of 42.7% ($\frac{64}{150}$). Thus, there will be a 42.7% chance that the climate event occurs in your group.
- If the computer randomly draws Urn C, the final composition of the urn will thus be of 44 black balls ($105-61=44$) and of 106 white balls ($45+61=106$). The probability of occurrence of the climate event will then be of 29.3% ($\frac{44}{150}$). Thus, there will be a 29.3% chance that the climate event occurs in your group.

If Urn A is drawn and no one invests in mitigation, the probability of a climate event occurring is equal to 96.7%; on the contrary, if the 4 group members invest all of their tokens in mitigation, the probability decreases down to 30%.

If Urn B is drawn and no one invests in mitigation, the probability of a climate event occurring is equal to 83.3%; on the contrary, if the 4 group members invest all of their tokens in mitigation, the probability decreases down to 16.7%.

If Urn C is drawn and no one invests in mitigation, the probability of a climate event occurring is equal to 70%; on the contrary, if the 4 group members invest all of their tokens in mitigation, the probability decreases down to 3.3%.

Information acquisition

In each period, before choosing your mitigation investment, you have the possibility to buy

information about the small urn that the computer will draw. To do so, you can **use up to 50 ECUs from your initial wealth** of 250 ECUs.

Task 0 \Rightarrow You will indicate on your tablet computer the maximal amount (between 0 and 50 ECUs, 5 ECUs by 5 ECUs) that you are willing to pay in order to obtain information. If you do not wish to obtain information, you will indicate 0 ECU.

Once you will have indicated your maximum price, the computer will randomly select an integer between 5 and 50 (by increments of 5) for your group. If the amount you indicated is higher than or equal to the number selected by the computer, then you obtain information about the drawn small urn **at the price fixed by the computer**. However, if your price is lower than the one of the computer, you do not obtain information and you pay nothing.

Task 2 \Rightarrow In each period, once you will have decided on the allocation of your climate budget, you will have to indicate what you think **the total investment in mitigation of the 3 other members of your group** will be for that period. If your answer is precise, you will receive 25 additional ECUs.

If your answer is exact or does not depart from the actual one by more than 7, you will earn 25 additional ECUs. If your answer departs from the actual one by more than 7, you will earn nothing.

Before making your information purchase and tokens' allocation decisions, you will also have to indicate which urn you think will be drawn.

The picture below (**Figure 3.1** and **Figure 3.2**) shows you how to indicate your level of investment in mitigation and your estimation of the level of investment of the 3 other members of your group.

On your screen, you will have 2 sliders:

- The top slider allows you to choose your level of investment in mitigation, that is, an integer between 0 and 25.
- The bottom slider allows you to choose your estimation of the level of investment of the 3 other members of your group in mitigation, which can vary from 0 to 75 tokens (75 being the maximal amount of tokens that the 3 other members of your group can invest in mitigation).

By modifying the position of the sliders, you will also obtain, on your screen, *the probability of occurrence of a climate event for each of the 3 small urns*.

Adaptation measures

Recall that the tokens you do not invest in mitigation will be automatically invested in adaptation.

Investments in adaptation serve to reduce the severity of the climate event **for yourself only**. In other words, by investing in adaptation, you can decrease the size of the loss of wealth you would incur if a climate event occurs.

Unlike mitigation measures, adaptation measures benefit only the person who makes the investments. Therefore, the size of the loss of wealth you will incur if a climate event occurs in your group **decreases only with your investment** in adaptation.

In order to help you understand how the size of the loss varies according to your decisions, you can refer to the adaptation table.

Let us take 2 examples **at random**:

Example 1: you decide to invest 6 tokens of your climate budget in adaptation. If the climate event occurs, the loss of wealth you will bear will be of 184.4 ECUs.

Example 2: you decide to invest 14 tokens of your climate budget in adaptation. If the climate event occurs, the loss of wealth you will bear will be of 163.6 ECUs.

Once each member will have estimated the total investment in mitigation of the 3 other group members, the computer will randomly draw a ball from the **small** urn in order to determine whether or not the climate event occurs.

The periods are independent from each other, meaning that if a climate event occurs in a period, it does not affect the probability of occurrence in the next ones.

Your gains

Your gains, in each period, are the sum of two amounts (gain for task 1 and gain for task 2) and depend on the occurrence of the climatic event:

The climate event does not occur	250 ECUs (your wealth) - information purchase + gain for task 2
The climate event occurs	250 ECUs (your wealth) - information purchase - size of the loss (see adaptation table) + gain for task 2

Let us take 1 example **at random** to explain your gains, without considering task 2:

You have a climate budget of 25 tokens. You decide to invest 16 tokens in mitigation and 9 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 176.6 ECUs. If your group is not hit by a climate event, your gains for task 1 amount, for that period, to 250 ECUs.

If your group is hit by a climate event, your gains for task 1 amount, for that period, to $250 - 176.6 = 73.4$ ECUs.

Let us take 2 examples **at random** to explain your gains, without considering task 2:

Example 1: You decide to buy information about the small urn for a maximum price of 15 ECUs. The amount selected by the computer is 35 ECUs. Since the price you indicated is lower than the number selected by the computer, you do not obtain information and you pay 0 ECU. Then, you have a climate budget of 25 tokens. You decide to invest 16 tokens in mitigation and 9 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 176.6 ECUs.

If your group is not hit by a climate event, your gains for task 1 amount, for that period, to 250 ECUs.

If your group is hit by a climate event, your gains for task 1 amount, for that period, to $250 - 176.6 = 73.4$ ECUs.

Example 2: You decide to buy information about the small urn for a maximum price of 20 ECUs. The amount selected by the computer is 10 ECUs. Since the price you indicated is higher than the number selected by the computer, you obtain information at the price of 10 ECUs. Then, you have a climate budget of 25 tokens. You decide to invest 3 tokens in mitigation and 22 tokens in adaptation. In case of a climatic event, you reduce the size of your loss to 142.8 ECUs.

If your group is not hit by a climate event, your gains for task 1 amount, for that period, to $250 - 10 = 240$ ECUs.

If your group is hit by a climate event, your gains for task 1 amount, for that period, to $250 - 142.8 = 107.2$ ECUs.

At the end of each period, you will be informed of **the small drawn urn**, the total investment of your group in mitigation, the resulting probability, the occurrence of the loss and your gains for that period.

At the end of the experiment, only 1 in 10 periods will actually be paid according to the conversion rate in euros. One participant will randomly draw a period in order to calculate the earnings for this first part. Each period has the same probability of being selected.

Before starting this part, you will have to complete a questionnaire designed to verify that you understood the instructions. Once completed, you will play in your group for 10 periods.

Figure 3.A: Adaptation table

Adaptation table
Amount of the loss (in ECUs) that you will have to bear if a climate event occurs according to your investment in mitigation

	Amount of the loss (in ECUs)
0	200.0
1	197.4
2	194.8
3	192.2
4	189.6
5	187.0
6	184.4
7	181.8
8	179.2
9	176.6
10	174.0
11	171.4
12	168.8
13	166.2
14	163.6
15	161.0
16	158.4
17	155.8
18	153.2
19	150.6
20	148.0
21	145.4
22	142.8
23	140.2
24	137.6
25	135.0

Values are rounded to 0.1.

ENVIRONMENTAL QUESTIONNAIRES

For that part, you will have to complete two questionnaires. Take your time to respond to the questions honestly and precisely. There is no good or wrong answer. We remind you that all your answers are anonymous and will be used only by the researchers involved in this project.

Answer by stating the frequency with which (never, rarely, sometimes, often, always):

1. You take shorter showers to save water.
2. You turn off the tap while brushing your teeth.
3. You only do your laundry with full loads.
4. You only run the dishwasher with full loads.
5. When you go to the toilet and there are two flush buttons, you use the small one.
6. You sort glass, plastic, paper, and metal.
7. You travel by foot, or use public transport/a bike to go to work, to go to school, to go shopping, etc.
8. You buy the organic alternative of a product when it is available.
9. You buy a product instead of another one because there is less packaging.
10. You buy a product instead of another one because it is produced locally.
11. You turn off the lights when you leave a room.
12. You use reusable bags when you do your grocery shopping.
13. You buy second-hand goods.
14. You disconnect devices in sleep mode.
15. You put on more clothes instead of increasing the heat when it gets cold.

Indicate if you agree or disagree with the following statements (strongly disagree, disagree, do not know, agree, strongly agree):

1. We are approaching the limit of the number of people the earth can support.
2. Humans have the right to modify the natural environment to suit their needs.
3. When humans interfere with nature it often produces disastrous consequences.
4. Human ingenuity will insure that we do NOT make the earth unlivable.
5. Humans are severely abusing the environment.
6. The earth has plenty of natural resources if we just learn how to develop them.
7. Plants and animals have as much right as humans to exist.
8. The balance of nature is strong enough to cope with impacts of modern industrial nations.
9. Despite our special abilities humans are still subject to the laws of nature.
10. The so-called "ecological crisis" facing humankind has been greatly exaggerated.
11. The earth is like a spaceship with very limited room and resources.

12. Humans were meant to rule over the rest of nature.
13. The balance of nature is very delicate and easily upset.
14. Humans will eventually learn enough about how nature works to be able to control it.
15. If things continue on their present course, we will soon experience a major ecological catastrophe.

PART 2

For this part, the conversion rate is **100 ECUs = 4 €**.

In this second part of the experiment, you will have 6 decisions to make.

You will be making a series of decisions about allocating resources between you and another person with whom you will be paired at the end of the experiment.

For each of the following tables which will appear on your screen, you will have to indicate, on your tablet computer, the distribution you prefer. You can choose only one distribution per table. There are no right or wrong answers, this is all about personal preferences. In the example below, if you choose distribution 3, you obtain a gain of 88 ECUs and the other participant, with whom you will be paired, receives 63 ECUs.

Distribution	Gain pour vous (ECUS)	Gain pour l'autre participant (ECUS)
1	100	50
2	94	56
3	88	63
4	81	69
5	75	75
6	69	81
7	63	88
8	56	94
9	50	100

Votre choix de distribution des gains

Votre choix : ▼

Your earnings for this part will depend on the table which will have been selected by a participant and will be the sum of two amounts: the amount in ECUs that you chose for yourself and the amount that the other participant, with whom you will be paired, chose to give you for the selected table.

[Displayed on the screen in a random order:]

	Table 1		Table 2		Table 3		Table 4		Table 5		Table 6	
	you	other	you	other	you	other	you	other	you	other	you	other
1	85	85	85	15	50	100	50	100	100	50	100	50
2	85	76	87	19	54	98	54	89	94	56	98	54
3	85	68	89	24	59	96	59	79	88	63	96	59
4	85	59	91	28	63	94	63	68	81	69	94	63
5	85	50	93	33	68	93	68	58	75	75	93	68
6	85	41	94	37	72	91	72	47	69	81	91	72
7	85	33	96	41	76	89	76	36	63	88	89	76
8	85	24	98	46	81	87	81	26	56	94	87	81
9	85	15	100	50	85	85	85	15	50	100	85	85

PART 3

For this part, there are two tasks. Only one of these 2 tasks will actually be paid at the end of the experiment. One participant will randomly draw a task in order to determine your gain for that third part. Each task has the same probability of being selected.

Before beginning this third part, you will have to choose your winning color: yellow or blue.

Task 1

You will be making a series of decisions which consists of choosing between two options, the Left option whose outcome is uncertain and the Right option whose outcome is certain.

The Left option consists of a random draw of a ball from an urn comprised of 5 yellow balls and 5 blue balls. If the randomly drawn ball is the same color as your winning color, you will earn 10€. If the randomly drawn ball is not the same color, you will earn 0€.

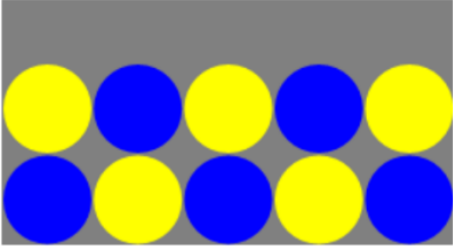
The Right option, however, yields an amount X with certainty, X going from 0€ to 10€. Note: If you prefer the Left option for a given amount X , then it will be the same for all the amounts lower than X . Similarly, if you prefer the Right option for a given amount X , then it will be the same for all the amounts higher than X . The computer will also force you to choose the Left option for X equal to 0€, and to choose the Right option for X equal to 10€.

Example with yellow as the winning color.

Left Option: The urn contains 5 yellow balls et 5 blue balls.

Remind: Your winning color is ●

Please, choose between the Left Option (uncertain outcome) and the Right Option (sure outcome of X€).

Left Option: Play the lottery below	Left	Right	Right option: Receive with certainty an amount X =
 <p>10€ gain if ● 0€ gain if ●</p>	<input type="radio"/>	<input checked="" type="radio"/>	0€
	<input type="radio"/>	<input type="radio"/>	1€
	<input type="radio"/>	<input type="radio"/>	2€
	<input type="radio"/>	<input type="radio"/>	3€
	<input type="radio"/>	<input type="radio"/>	4€
	<input type="radio"/>	<input type="radio"/>	5€
	<input type="radio"/>	<input type="radio"/>	6€
	<input type="radio"/>	<input type="radio"/>	7€
	<input type="radio"/>	<input type="radio"/>	8€
	<input type="radio"/>	<input type="radio"/>	9€
	<input type="radio"/>	<input checked="" type="radio"/>	10€

Your gains:

In the first instance, you will randomly select the line which will determine the amount X. Then,

- if, for that line, you selected the **Left** option, a ball will be drawn from the urn. If that ball is the same color as your winning color, you will earn 10€, otherwise, you will earn 0€.
- if, for that line, you selected the **Right** option, you will earn the amount of X€.

Task 2

For this second task, you will be making a series of decisions which consists of choosing between two options, the Left option whose outcome is uncertain and the Right option whose outcome is certain.

The Left option consists of a random draw of a ball from an urn comprised of **10 balls**. You will **not know the number of yellow and blue balls** in the urn. The unknown urn can therefore contain from 0 to 10 yellow balls and from 0 to 10 blue balls. If the randomly drawn ball is the same color as your winning color, you will earn 10€. If the randomly drawn ball is not the same color, you will earn 0€.

The Right option, however, yields an amount X with certainty, X going from 0€ to 10€. Note: If you prefer the Left option for a given amount X, then it will be the same for all the amounts

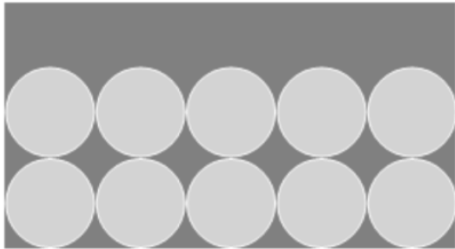
lower than X . Similarly, if you prefer the Right option for a given amount X , then it will be the same for all the amounts higher than X . The computer will also force you to choose the Left option for X equal to 0€ , and to choose the Right option for X equal to 10€ .

Example with yellow as the winning color.

Left Option: The urn contains 10 balls, of which the number of yellow and blue balls is unknown.

Remind: Your winning color is ●

Please, choose between the Left Option (uncertain outcome) and the Right Option (sure outcome of $X\text{€}$).

Left Option: Play the lottery below	Left	Right	Right option: Receive with certainty an amount $X =$
 <p>10€ gain if ● 0€ gain if ●</p>	<input type="radio"/>	<input checked="" type="radio"/>	0€
	<input type="radio"/>	<input type="radio"/>	1€
	<input type="radio"/>	<input type="radio"/>	2€
	<input type="radio"/>	<input type="radio"/>	3€
	<input type="radio"/>	<input type="radio"/>	4€
	<input type="radio"/>	<input type="radio"/>	5€
	<input type="radio"/>	<input type="radio"/>	6€
	<input type="radio"/>	<input type="radio"/>	7€
	<input type="radio"/>	<input type="radio"/>	8€
	<input type="radio"/>	<input type="radio"/>	9€
	<input type="radio"/>	<input checked="" type="radio"/>	10€

Your gains:

In the first instance, you will randomly select the line which will determine the amount X . Then,

- if, for that line, you selected the **Left** option, a ball will be drawn from the urn. If that ball is the same color as your winning color, you will earn 10€ , otherwise, you will earn 0€ .
- if, for that line, you selected the **Right** option, you will earn the amount of $X\text{€}$.

POST-EXPERIMENTAL QUESTIONNAIRE

1. Your age:

2. Your sex: *Male; Female; Other*

3. Your degree: *Bachelor; Master; PhD*

4. Your field of study: *Law; Economics and Management; Literature and Languages; Hard sciences; Psychology and Sociology; Political science; Other (please specify)*

5. In everyday life, do you think that you are a person who rather takes risks or a rather careful person? Please indicate on a scale of 0 to 10 where do you think you stand; 0

standing for a very careful person and 10 for a person who loves taking risks. 0; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10

6. In everyday life, do you think that you try to help other people or that you only care about your own concerns? Please indicate on a scale of 0 to 10 where do you think you stand; 0 standing for a person who loves helping others and 10 for a person who acts in their own interest. 0; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10

7. In everyday life, do you think that people try to help others or that they only care about their own concerns? Please indicate on a scale of 0 to 10 where do you position other people; 0 standing for a person who loves helping others and 10 for a person who acts in their own interest. 0; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10

8. Generally speaking, do you think that we can trust most people or that we must be very careful with people? *We can trust most people; We must be very careful with people*

9. During the second part of the experiment, which information did guide your decisions? *Only your payoff; Your payoff and others' payoff such that they do not have less than you; Your payoff and others' payoff such that they do not have more than you; Your payoff and others' payoff such that they have no more and no less than you*

10. Which criteria did guide your decisions during the experiment?

11. In your opinion, what was the objective of this experiment?

Conclusion

Environmental risks have become a serious threat to our societies. The increased frequency and severity of those risks have placed their management at the forefront of the public debate. We can refer, for example, to the explosion of ammonium nitrate stored at the port of Beirut in August 2020, or to the different heatwaves of summer 2022 and the consequent droughts and forest fires (e.g., approximately 27 000 hectares burned in Gironde (France), 4 000 hectares burned in Galicia (Spain), 2 000 hectares burned in Attica (Greece)), to name but a few. In the face of such public bads, the three chapters of this thesis were devoted to finding ways to collectively reduce the probability of environmental risks occurring.

The **first chapter** assessed the pertinence of the information disclosure mechanism as a means of managing environmental harms. While most studies find a positive impact of this mechanism (Blackman et al., 2004; Powers et al., 2011; Huet-Vaughn et al., 2018; Pien, 2020), this chapter aimed at understanding whether this result still holds true when information disclosure complements existing liability sharing rules. To do so, we ran a laboratory experiment wherein subjects, in groups of four, must decide on their level of investment in safety to avoid a common loss. Investments were costly and allowed subjects to decrease the probability of causing harm to the environment. In case of damage occurring, the loss was apportioned among the group members according to the liability sharing rule (i.e., per capita or proportional). We thus looked at the effect of information disclosure under a per capita rule and a proportional rule of liability. The results showed that the efficiency of the information disclosure mechanism actually depends on the legal context. Indeed, we found that information disclosure has a positive impact on the investments in safety when a per capita rule applies but has no effect under a proportional rule. We explained it by the fact that a low contribution under a per capita rule of liability induces a clear signal of being little concerned by the consequences of this small investment. This finding

somehow challenges the results of previous papers which indicate that information disclosure has a positive effect on firms' environmental performance since we stated that it might depend upon the existing regulatory measures. Another interesting result was that a per capita rule with information disclosure appears to be as efficient as a proportional rule without information disclosure. This finding might be useful for public policy. Indeed, implementing a per capita rule of liability requires less information and involves less uncertainties for the firms than a proportional rule. Moreover, the disclosure of information may also come from private initiatives (e.g., NGOs, citizens), therefore relieving public authorities.

Obviously, the results of this experiment cannot be taken as conclusive evidence of the role of information disclosure and liability rules in managing environmental harms, and call for further research. For example, several extensions could be considered. First, a third party, able to make a value judgement, could be introduced. In this way, (dis)esteem from others would become more salient. Second, it would be interesting to consider pecuniary sanctions along with the mechanism of information disclosure. It could indeed better reflect the fact that firms can incur losses due to tarnished images.

The **second chapter** focused on the role of inequalities in the fight against climate change. We considered two different policies to tackle climate change, namely mitigation and adaptation measures. In a laboratory experiment, subjects, in groups of four, must decide on the allocation of their resources between reducing the probability of a climate event occurring for every group member (i.e., mitigation), and decreasing the severity of the loss they would suffer in case of a climate damage for themselves only (i.e., adaptation). Between treatments, we redistributed the resources within groups so as to increase the degree of inequality. The objective of this chapter was to assess the effects of deepening inequalities on the mitigation-adaptation trade-off. The results showed no difference in group contributions to mitigation between treatments, meaning that the degree of inequality does not affect contributions at the group-level. We found that subjects contribute to mitigation by adjusting to the 'fair-share' rule, which is equivalent, in this experiment, to investing the same share of resources as everyone else in the group. We also highlighted the major role of social preferences in the choice to mitigate or to adapt to climate change of rich subjects. The interesting finding is that rich subjects do not react to the actual level of inequality but rather to the way they perceive inequality, that is to say, to whether they see inequality as a 'bad thing' (i.e., they are averse to inequality) or not (i.e., they are not

averse to inequality). A valuable extension of this experiment would be to impose minimum-contribution requirements as in Keser et al. (2017), which is similar to the ‘taxes’ implemented in Andreoni (1993). Different minimum-contribution schemes could be considered: a lump-sum tax (subjects must contribute the same amount of resources regardless of their type), a flat tax rate (subjects must contribute the same proportion of their resources regardless of their type), or a progressive tax (wealthiest subjects must contribute a higher share of their resources). This should contribute to a better understanding of the effects of the different schemes on subjects’ sense of justice and their willingness to cooperate in the fight against climate change.

Also, in the mitigation-adaptation trade-off, each measure combines two dimensions. Mitigation is a *collective* measure that acts on the *probability* of occurrence of the climate disaster, while adaptation is an *individual* measure that acts on the *outcome* of the disaster. Therefore, the choice of one measure rather than the other might be driven by different motivations. It could be valuable for public policy to determine which dimension should be emphasized in order to maximize public support. An experiment would allow for the disentanglement of these effects.

The **third chapter** also experimentally examined the choice to mitigate or to adapt to climate change. In this chapter, we considered a risky context and an ambiguous one with respect to the probability of occurrence of a climate event. In the risky situation, subjects, in groups of four, perfectly knew the probability of a climate damage occurring. However, in the ambiguous situation, subjects did not know which probability distribution they would face, so that the probability of occurrence of a climate disaster was ambiguous. We also ran a treatment wherein subjects could pay to obtain information about the actual probability distribution, allowing them to completely reduce ambiguity. In this way, we were able to obtain a measure of their willingness to pay to eliminate ambiguity. The results brought to light two interesting points. First, subjects’ preferences toward risk and ambiguity matter in the mitigation-adaptation trade-off. We stated that those preferences should therefore be taken into consideration in order to design efficient climate policies. Second, we found that, most of the time, subjects are willing to pay to get information that eliminates ambiguity and that they actually use it when they receive it. This highlights the importance of providing individuals with (high quality) information on climate change.

Here again, more research needs to be conducted in order to grasp the role of uncertainties in the choice to mitigate or to adapt to climate change. An interesting extension that could

be pursued would be to introduce uncertainty with regard to the efficiency of investments in mitigation. Indeed, there exist a lot of uncertainties as to the link between actions (curtailment of greenhouse gaz emissions) and consequences (expected damage due to climate change) (Boucher and Bramoullé, 2010). This experimental design would shed light on the point at issue while also depicting a real-life situation.

In light of the seriousness of the current situation, more research is needed in order to comprehend behaviors toward public bads. While the literature on public goods games is abundant, it would be useful to enrich the literature on public bads in order to understand situations which hinder cooperation and mechanisms that could be implemented to recover it. In this way, we could determine the extent to which findings from the public goods games literature can be transposed to public bad settings.

Bibliography of the Conclusion

- Andreoni, J. (1993). An Experimental Test of the Public-Goods Crowding-Out Hypothesis. *The American Economic Review*, 83(5):1317–1327.
- Blackman, A., Afsah, S., and Ratunanda, D. (2004). How do public disclosure pollution control programs work? evidence from indonesia. *Human Ecology Review*, 11(3):235–246.
- Boucher, V. and Bramoullé, Y. (2010). Providing global public goods under uncertainty. *Journal of Public Economics*, 94(9):591–603.
- Huet-Vaughn, E., Muller, N., and Hsu, Y.-C. (2018). Livestreaming pollution: a new form of public disclosure and a catalyst for citizen engagement? NBER working paper 24664.
- Keser, C., Markstädter, A., and Schmidt, M. (2017). Mandatory minimum contributions, heterogeneous endowments and voluntary public-good provision. *Games and Economic Behavior*, 101:291–310.
- Pien, C.-P. (2020). Local environmental information disclosure and environmental non-governmental organizations in chinese prefecture-level cities. *Journal of Environmental Management*, 275.
- Powers, N., Blackman, A., Lyon, T. P., and Narain, U. (2011). Does disclosure reduce pollution? evidence from india’s green rating project. *Environment and Resource Economics*, 50:131–155.

Résumé long

L'évolution des sociétés, qui passe notamment par la mondialisation, la croissance économique, l'urbanisation, etc., les expose à de plus en plus de risques. En particulier, les sociétés sont devenues davantage vulnérables aux risques environnementaux. Les exemples de tels risques sont nombreux : la pollution de l'air, l'éruption du volcan Sakurajima au Japon en juillet 2022, le changement climatique, l'incendie de l'usine AZote Fertilizants en 2001 à Toulouse, les canicules de juillet et août 2022, etc. L'augmentation de la fréquence et de l'intensité de ces risques requiert des actions immédiates de la part des gouvernements et des citoyens.

Avant de définir les risques environnementaux, il convient d'abord de définir la notion de risque. En général, le risque résulte de la combinaison de deux éléments : la probabilité qu'un événement indésirable se produise et les conséquences néfastes de cet événement. Les risques environnementaux peuvent donc être définis comme des événements extrêmes qui libèrent des concentrations d'énergie ou de matières dans l'environnement à une échelle suffisamment grande pour constituer des menaces majeures pour la vie humaine et les actifs économiques. Il existe trois sortes de risques environnementaux : les risques naturels, les risques technologiques et les risques liés au contexte¹. Dans cette analyse, nous nous concentrons uniquement sur les deux derniers types de risques, à savoir les risques technologiques et les risques liés au contexte. Concernant les risques technologiques, le dernier incident majeur, en France, remonte à septembre 2019 avec l'incendie de l'entreprise Lubrizol à Rouen. Pour ce qui est des risques liés au contexte, il suffit simplement de penser aux conséquences liées au changement climatique qui s'aggrave.

En mobilisant l'économie expérimentale, le but de ce travail est d'apporter des recommandations en matière de politique publique afin de limiter la survenance de ces risques. Plus particulièrement, cette thèse vise à trouver des moyens pour réduire collectivement la probabilité que ces risques se produisent. Le premier chapitre s'intéresse aux risques technologiques et aux firmes. Les deuxième et troisième chapitres portent sur les décisions des individus dans le contexte du changement climatique. Dans le deuxième chapitre, l'analyse

¹Le terme anglais est *context hazards*.

se concentre sur l'effet des inégalités de richesse alors que le troisième chapitre étudie le rôle du risque, de l'ambiguïté et de l'achat d'informations.

Le premier chapitre s'intéresse à la stratégie de divulgation d'informations comme moyen pour prévenir les dommages environnementaux causés par un groupe d'agents. Dans le cas de dommages environnementaux, ces mécanismes ne peuvent venir qu'en complément des réglementations déjà en place en termes de responsabilité civile. En effet, lorsque plusieurs auteurs sont à l'origine d'un même dommage, il convient alors de répartir le préjudice entre ces agents selon les règles de responsabilité civile. Aux Etats-Unis, on retrouve, dans le CERCLA², la règle proportionnelle pour allouer les parts de responsabilité aux multiples auteurs du dommage en fonction des précautions prises par chacun, alors que la plupart des pays européens sont soumis à la règle égalitaire du partage de responsabilité, ce qui implique que les auteurs assument une part identique du dommage, quel que soit leur niveau de précaution. Au moyen d'une expérience en laboratoire, nous comparons l'efficacité de la divulgation d'informations lorsqu'elle s'applique à une règle proportionnelle, et lorsqu'elle s'applique à une règle égalitaire du partage de la responsabilité. Les sujets, répartis en groupes de quatre, doivent décider quel niveau de précaution ils souhaitent prendre afin de diminuer la probabilité qu'un dommage se produise au sein de leur groupe. S'il survient, le dommage est entièrement compensé et est réparti entre les membres du groupe selon la règle mise en place. Chaque sujet dispose d'une richesse initiale qui lui permet d'être solvable ainsi que d'une dotation qu'il peut décider d'investir ou non dans les mesures de précaution. Les investissements sont coûteux puisqu'ils diminuent le montant de la dotation. Lorsque la divulgation d'informations s'applique, le prénom et la photographie des sujets ayant le moins investi sont diffusés sur l'écran de tous les participants à la fin de l'expérience, de manière à ouvrir la voie à la désapprobation sociale de la part des autres participants.

Nous montrons que la divulgation d'informations n'est efficace que lorsqu'elle s'applique à un régime de partage de la responsabilité égalitaire. En effet, avec une règle égalitaire, les faibles contributeurs imposent une externalité aux autres membres de leur groupe qui est plus élevée qu'avec une règle proportionnelle, entraînant ainsi une désapprobation

²CERCLA : Comprehensive Environmental Response, Compensation and Liability Act.

plus importante. Bien qu'une règle proportionnelle incite à prendre davantage de mesures préventives qu'une règle égalitaire, la divulgation d'informations, lorsqu'elle vient en complément d'une règle égalitaire, permet d'atteindre le même niveau de précautions qu'une règle proportionnelle. Ce résultat s'avère intéressant en termes de politique publique car, d'une part, l'instauration d'une règle égalitaire requiert moins d'informations à collecter et, d'autre part, suppose moins d'incertitudes pour les firmes qu'une règle proportionnelle. Dans le second chapitre, nous analysons, toujours au moyen d'une expérience en laboratoire, le comportement des sujets lorsqu'ils font face au changement climatique, en fonction du niveau d'inégalité au sein de la société. Le changement climatique représente un enjeu majeur qu'il est impératif de maîtriser. Il existe deux types de mesures qui peuvent être prises à cet effet : les mesures d'atténuation (autoprotection) et d'adaptation (auto-assurance). Les mesures d'atténuation visent à diminuer la probabilité de survenance du dommage. Dans le cadre du changement climatique, il est possible d'imaginer qu'un individu choisisse de prendre les transports en commun plutôt que sa voiture pour se déplacer afin de limiter ses émissions de gaz à effet de serre ou encore qu'il décide de réduire et trier ses déchets. En revanche, les mesures d'adaptation permettent de réduire l'ampleur du dommage s'il survient uniquement pour l'individu qui choisit de prendre de telles mesures. Dans le cas du changement climatique, il peut s'agir, par exemple, de la pose d'un drain autour de sa maison pour faire face à de potentiels épisodes pluvieux plus intenses. De nombreuses études montrent que, pour diverses raisons, les groupes défavorisés seront davantage impactés par le changement climatique. L'objectif de ce chapitre est donc d'étudier le rôle des inégalités dans le choix d'adopter des mesures d'atténuation ou d'adaptation au changement climatique. Pour ce faire, les sujets interagissent au sein d'un groupe de quatre personnes et sont assignés à un type (riche ou pauvre). En fonction de ce type, ils sont dotés d'une certaine richesse en ECUs³ et d'un budget climat en jetons. Chaque groupe fait face à un risque de subir un événement climatique qui peut causer une perte de richesse identique pour tous les membres. Les sujets doivent décider de l'allocation de leur budget climat entre les deux mesures. Un jeton investi en atténuation permet de diminuer la probabilité de survenance de l'événement climatique pour

³ECUs : Experimental Currency Units. Il s'agit de l'unité monétaire expérimentale.

l'ensemble du groupe alors qu'un jeton investi en adaptation permet au sujet de diminuer le montant de sa perte personnelle en cas de survenance de l'événement climatique. Puisque nous nous intéressons à l'effet d'une augmentation des inégalités sur les décisions d'atténuation et d'adaptation, d'un traitement à l'autre, nous modifions la distribution de richesses et de jetons au sein des groupes afin d'introduire un certain degré d'inégalité de manière graduelle. Il en résulte quatre traitements. Le premier traitement est un traitement sans inégalité où le coefficient de Gini⁴ est nul. Dans les trois autres traitements, le coefficient passe à 0,15 puis à 0,225 et enfin à 0,3.

Les résultats montrent que l'investissement moyen en atténuation au sein des groupes n'est pas influencé par le niveau d'inégalité. En effet, les sujets investissent tous la même proportion de leur budget climat en atténuation quel que soit leur type. Ils semblent se conformer à la *fair share rule*. Nous trouvons aussi que les préférences sociales (mesurées par le degré d'aversion à l'inégalité) jouent un rôle important, notamment chez les riches, dans le choix d'atténuer ou de s'adapter au changement climatique. En réalité, nous montrons que ces derniers ne répondent pas au degré d'inégalité en tant que tel mais plutôt à la manière dont ils perçoivent les inégalités.

Le troisième chapitre constitue une extension du deuxième. Nous étudions toujours la relation entre les mesures d'atténuation et d'adaptation en envisageant, cette fois-ci, un cadre risqué et un cadre ambigu concernant la probabilité de survenance de l'événement climatique. En effet, le changement climatique introduit de nombreuses incertitudes et notamment une incertitude sur la fréquence de ces événements. Dans ce cas, on parle alors d'ambiguïté. L'ambiguïté fait référence à des situations où la probabilité n'est pas parfaitement connue. L'objectif de ce chapitre est de placer les sujets dans une situation où ils ne savent pas parfaitement à quelle distribution de probabilité ils font face (ambiguïté) et de comparer cette situation à celle où il n'y a pas d'ambiguïté sur la probabilité (risque). Dans le traitement sans ambiguïté, les sujets sont soumis à une seule distribution de probabilité pour la survenance de l'événement climatique. La probabilité de subir un événement climatique est représentée par des boules disposées dans une urne qui est

⁴L'INSEE (Institut National de la Statistique et des Etudes Economiques) définit le coefficient de Gini comme "un indicateur synthétique permettant de rendre compte du niveau d'inégalité pour une variable et sur une population donnée".

initialement constituée d'un certain nombre de boules noires et blanches. Si une boule noire est tirée de l'urne, cela signifie qu'un événement climatique se produit au sein du groupe. En revanche, si la boule tirée est blanche, il n'y a pas d'événement climatique. Chaque jeton investi en atténuation a comme effet de remplacer une boule noire de l'urne par une boule blanche. Dans le traitement avec ambiguïté, il y a trois distributions de probabilité potentielles, autrement dit, il y a trois urnes qui diffèrent selon leur composition initiale en boules noires et blanches. De cette manière, les sujets ne savent pas parfaitement dans quel état de la nature ils se trouvent lorsqu'ils prennent leurs décisions d'atténuation et d'adaptation. Nous adressons également la question de la réduction de l'ambiguïté. En effet, dans le dernier traitement, les sujets ont la possibilité d'acheter de l'information réduisant complètement l'ambiguïté, les faisant ainsi passer d'un cadre ambigu à un cadre risqué. Le prix à payer pour acheter l'information nous donne une indication sur leur consentement à payer pour éliminer l'ambiguïté.

Les résultats ne montrent aucune différence dans les contributions moyennes à l'atténuation entre les différents traitements. Nous l'expliquons par le fait que les sujets sont, en moyenne, neutres vis-à-vis du risque et de l'ambiguïté (i.e., ils n'ont pas de goût ni d'aversion au risque ni à l'ambiguïté). Au niveau individuel, nous mettons en évidence le rôle des préférences pour le risque et l'ambiguïté dans l'arbitrage entre les mesures d'atténuation et d'adaptation. Nous constatons également que, plus de la moitié du temps, les sujets sont prêts à payer pour obtenir de l'information permettant d'éliminer l'ambiguïté. L'intensité de leur propension à payer est positivement corrélée à l'aversion à l'ambiguïté, ce qui signifie que plus un sujet est averse à l'ambiguïté, plus il valorise l'information. Nous concluons qu'il serait bénéfique de fournir des informations aux individus afin de réduire l'ambiguïté liée au changement climatique puisque nous constatons également que les sujets ayant accès à l'information l'utilisent. Ils modifient leur comportement en fonction de l'état de la nature dans lequel ils se trouvent.

Titre: Prévention des risques environnementaux: une approche expérimentale

Mots clés: Risques environnementaux; Maux publics; Prévention collective; Expériences en laboratoire

Résumé: L'évolution des sociétés, qui passe notamment par la mondialisation, la croissance économique, l'urbanisation, etc., les expose à de plus en plus de risques. En particulier, les sociétés sont devenues davantage vulnérables aux risques environnementaux. Les exemples de tels risques sont nombreux : la pollution de l'air, le changement climatique, l'incendie de l'usine AZote Fertilizants, les canicules de juillet et août 2022, etc.

Grâce à l'économie expérimentale, le but de cette thèse est d'apporter des recommandations en matière de politique publique afin de limiter la survenance de ces événements. Plus particulièrement, cette thèse vise à trouver des moyens pour réduire collectivement la probabilité que ces risques se produisent.

Le premier chapitre évalue l'efficacité de la divulgation d'informations comme moyen de prévention des dommages environnementaux causés par un groupe d'agents. L'intérêt de ce chapitre est de déterminer dans quelle mesure ce mécanisme peut s'avérer efficace lorsqu'il vient en complément des réglementations déjà en place en termes de responsabilité civile. En effet, lorsque plusieurs auteurs sont à l'origine d'un même dommage, il convient de répartir le préjudice entre ces agents selon les règles de partage de la responsabilité. Au moyen d'une expérience en laboratoire, nous comparons l'efficacité de la divulgation d'informations lorsqu'elle s'applique à une règle égalitaire du partage de responsabilité et à une règle proportionnelle. Les résultats montrent que la divulgation d'informations n'est efficace que

lorsqu'elle s'applique à un régime de partage de la responsabilité égalitaire.

Dans le deuxième chapitre, nous analysons, au moyen d'une expérience en laboratoire, les effets des inégalités de richesse sur le type d'effort que les individus sont prêts à faire pour lutter contre le changement climatique. Les sujets doivent déterminer l'allocation de leurs ressources entre les politiques d'atténuation et d'adaptation. D'un traitement à l'autre, nous modifions la distribution des ressources au sein des groupes de manière à faire varier le degré d'inégalité. Nous montrons que le degré d'inégalité ne modifie pas les contributions de groupe à l'atténuation. Il se trouve que les sujets se conforment à la *fair share rule* et investissent tous la même proportion de leur ressources en atténuation.

Le troisième chapitre constitue une extension du deuxième. Nous étudions toujours la relation entre les mesures d'atténuation et d'adaptation en envisageant, cette fois-ci, un cadre risqué et un cadre ambigu par rapport à la probabilité de survenance d'un événement climatique. Nous adressons également la question de la réduction de l'ambiguïté. En effet, dans le dernier traitement, les sujets ont la possibilité d'acheter de l'information afin d'éliminer l'ambiguïté. Les résultats ne montrent pas de différence entre les traitements au niveau des contributions moyennes en atténuation. Au niveau individuel, nous mettons en évidence le rôle des préférences vis-à-vis du risque et de l'ambiguïté dans le choix d'atténuer ou de s'adapter au changement climatique.

Title: Prevention of environmental risks: an experimental approach

Keywords: Environmental risks; Public bads; Collective prevention; Laboratory experiments

Abstract: The developments of societies that take place through globalization, economic expansion, urban sprawl, etc., increasingly expose them to various risks. In particular, they have become more vulnerable to environmental risks. Examples of such risks abound: air pollution, climate change, the fire at the AZote Fertilizants company, the heatwaves of July and August 2022, etc.

Thanks to experimental economics, the objective of this thesis is to provide policy recommendations in order to limit the occurrence of such bad events. More precisely, this thesis aims at finding ways to collectively reduce the probability of these risks occurring.

The first chapter looks at the efficiency of information disclosure as a means of managing environmental harms jointly caused by a group of agents. The interest of this chapter is to determine the extent to which this mechanism is useful when it complements existing liability rules. Indeed, when several tortfeasors are responsible for a common damage, liability must be apportioned among them according to the liability sharing rules. By means of a laboratory experiment, we compare the efficiency of information disclosure when it complements a per capita rule of liability and a proportional rule of liability. The results show that the disclosure mecha-

nism is efficient only when it complements a per capita rule.

In the second chapter, we experimentally analyze the effects of income inequalities on the type of effort individuals are willing to make in order to face climate change. Subjects must decide on the allocation of their resources between mitigation policies and adaptation policies. Between treatments, we modify the distribution of resources within groups so as to increase the degree of inequality. We find that the degree of inequality does not affect group contributions to mitigation. It seems that subjects comply with the *fair share rule*, that is, they invest the same share of their resources in mitigation.

The third chapter constitutes an extension of the second one. We still study the trade-off between mitigation and adaptation, considering, this time, a risky context and an ambiguous one with regard to the probability of occurrence of a climate event. We also address the question of the reduction of ambiguity. Indeed, in the last treatment, subjects have the possibility to buy information in order to eliminate ambiguity. The results show no difference in average contributions to mitigation between treatments. At the individual level, we highlight the role of preferences toward risk and ambiguity in the choice to mitigate or to adapt to climate change.

Université de Lorraine

Faculté de Droit, Sciences Economiques et Gestion de Nancy

13 Place Carnot - C.O. 700 26

54035 Nancy cedex

France